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A LIMITED STUDY OF THE PERFORMANCE OF AN INTERIM 3/4-TON WHEEL/TRACK CONVERTIBLE TEST RIG, HOUGHTON, MICHIGAN, AND VICKSBURG, MISSISSIPPI

ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

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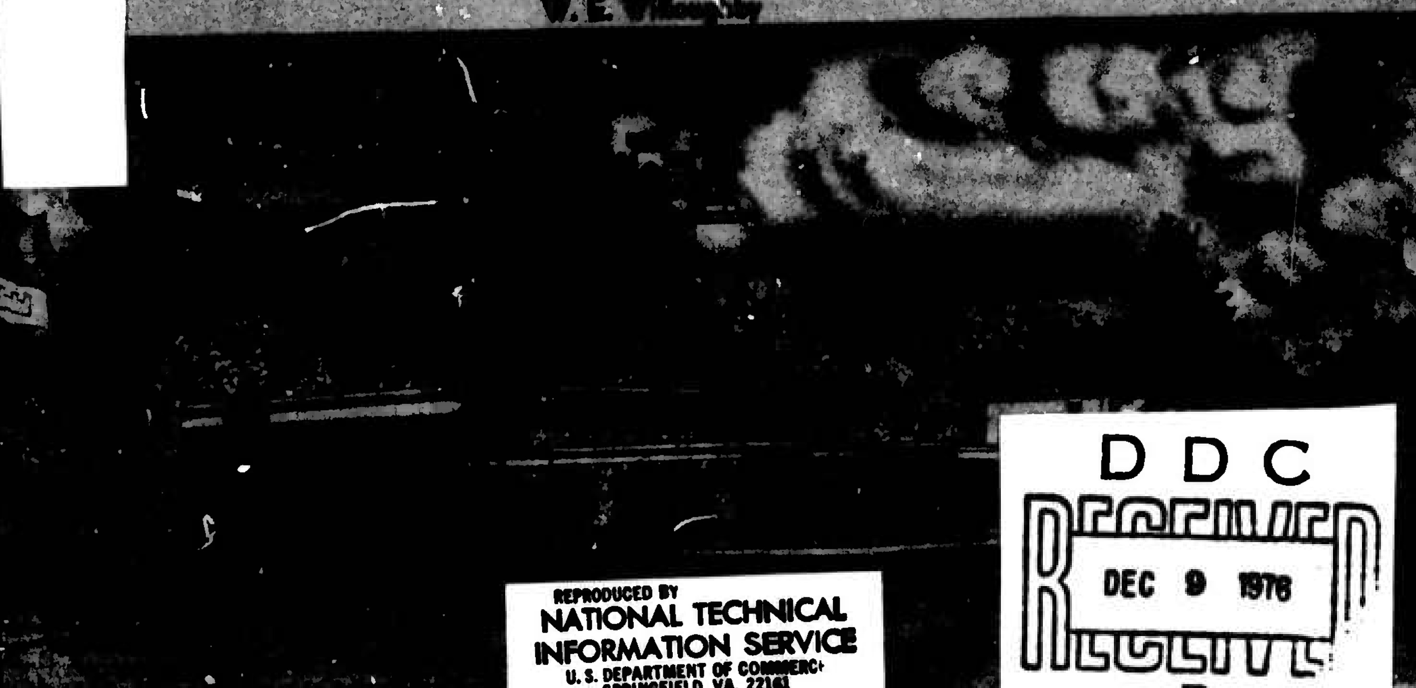

April 1974

Sponsored by U. S. Army Materiel Command and
U. S. Army Tank-Automotive Command
Conducted by U. S. Army Engineer Waterways Experiment Station
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ARMY-MRC VICKSBURG, MISS

FOREWORD

The test program reported herein was requested by Headquarters, U. S. Army Materiel Command and funded through the U. S. Army Tank-Automotive Command (TACOM) by Intra-Army Order for Reimbursable Services, No. 72-3R, dated 14 June 1972. It was conducted during May-October 1973 by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) and TACOM under the general supervision of Messrs. W. G. Shockley, Chief of the Mobility and Environmental Systems Laboratory (MESL), WES; A. A. Rula, Chief of the Mobility Systems Division (MSD), MESL; and E. S. Rush, Chief of the Mobility Investigations Branch (MIB), MSD; and Tibor Czako, Surface Mobility Division, TACOM. Field tests were performed near Houghton, Michigan, and Vicksburg, Mississippi, under the direction of Messrs. W. E. Willoughby of the MIB and J. F. Kopera, Concept and Technology Division, TACOM. Mr. Willoughby prepared this report.

Acknowledgments are made to personnel of TACOM, builders of the test rig, and of Keweenaw Field Station at Houghton for assistance and support during the tests.

COL G. H. Hilt, CE, was Director of the WES during the test program and preparation of the report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC AND METRIC TO BRITISH UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	by	To Obtain
	British to Metric	
inches	25.4	millimeters
feet	0.3048	meters
feet per minute	0.3048	meters per minute
pounds (mass)	0.45359	kilograms
pounds (force)	4.4482	newtons
tons (2000 lb)	907.185	kilograms
square inches	645.16	square millimeters
pounds per square inch	6.894757	kilopascals
pounds per cubic foot	0.0160	grams per cubic centimeter
miles per hour	1.609344	kilometers per hour
miles (U. S. statute)	1.6093	kilometers
cubic inches	16.3871	cubic centimeters
	Metric to British	
millimeters	0.0394	inches
centimeters	0.3937	inches

SUMMARY

The interim Wheel/Track Convertible Test Rig, a uniquely suspended 8x8 wheeled vehicle that uses wrap-around tracks for improved performance, was tested in a variety of terrain conditions at Houghton, Michigan, and at Vicksburg, Mississippi, and in soil bins in a facility at Vicksburg. Tests were conducted to: evaluate the feasibility of the concept, determine if the track would stay on, observe interaction at the wheel-track interface to determine any possible slippage, determine ride and handling characteristics of the Wheel/Track Test Rig, which uses powered road arm suspensions, and evaluate and compare performance of the Test Rig with that of other available vehicles in tests on trails, cross-country traverses, special terrain, and laboratory-prepared soils.

The Wheel/Track Test Rig performed well in a variety of terrain conditions; generally its performance equaled or exceeded the performance of both wheeled and tracked comparison vehicles. Vehicle ride and handling characteristics were considered better than those of the comparison vehicles. Test rig performance in soil in the wheel mode was impressive: a drawbar pull/weight coefficient of 0.96 was obtained on a clay soil prepared in the laboratory to a strength of 66 RCI, and a field experimental one-pass vehicle cone index of 11 was obtained. No wheel-track slip occurred during any of these tests, including tests on soft buckshot clay in which the vehicle running gear accumulated 1600 lb of mud (on a 6700-lb vehicle).

Based on these tests, the Wheel/Track Convertible locomotion system is practicable, and the ride, handling, and performance of the Wheel/Track Test Rig suggest advanced testing, following any future design modifications.

Appendix A presents the plan of tests followed in this program.

A LIMITED STUDY OF THE PERFORMANCE OF AN INTERIM 3/4-TON WHEEL/TRACK CONVERTIBLE TEST RIG HOUGHTON, MICHIGAN, AND VICKSBURG, MISSISSIPPI

PART I: INTRODUCTION

Background

1. An exploratory development effort was initiated by the U. S. Army Tank-Automotive Command (TACOM) in fiscal year 1972 to determine the feasibility of using a wheel/track convertible concept to attain a major improvement in off-road surface mobility and tactical and logistical flexibility. The original concept was an 8x8 wheeled vehicle with infinite-variable-ratio steering. It could be readily converted to a tracked vehicle for soft-soil and snow mobility whenever the season or major terrain area required. An interim 3/4-ton* test rig powered by a differential-gear-steered power train was subsequently designed and fabricated by TACOM to assess the critical wheel-track interface, the unique integrated drive and trailing arm suspension system, and the skid-steer handling of the wheeled version. Upon satisfactory completion of the feasibility evaluation, it is tentatively planned to install a hydromechanical power train to assess the remaining critical area, that of high road speed-infinite variable ratio steer performance. This final configuration may satisfy Alaskan and infantry draft-load carrier requirements and future needs for high-mobility utility vehicles. This report covers the tests with the interim differential-gear-steered Test Rig, hereafter called Wheel/Track Convertible Test Rig, or simply Test Rig.

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* A table of factors for converting British units of measurement to metric units and metric units to British units is given on page ix.

Purpose and Scope

2. During May-October 1973, personnel of the U. S. Army Engineer Waterways Experiment Station (WES) and of TACOM conducted tests at Houghton, Michigan, and Vicksburg, Mississippi, to evaluate the practicability of the Wheel/Track Convertible Test Rig operating in various running-gear configurations and ground surface conditions and to compare its performance with that of several conventional wheeled and tracked vehicles. Appropriate data and test notes were recorded for each test configuration and surface condition to permit full evaluation of the Test Rig. The U. S. Army Materiel Command Ground Mobility Model (AMC-71)* was used as a basis for collecting vegetation and vehicle performance data. Results of the tests are summarized in this report. The requirements for a vehicle for which the Test Rig is a candidate are discussed in the background of the Test Plan for Wheel/Track Convertible Test Rig, 3/4-Ton (Appendix A).

Definitions

3. Certain special terms used in this report are defined below.

a. General terms

(1) Ground mobility. The ability of a ground contact vehicle to move across a landscape without benefit of roads or engineering assistance. Thus, a measure of ground mobility is a measure of the vehicle-terrain interaction.

(2) Trafficability test. A test conducted in a homogeneous area at low speeds to determine vehicle-terrain relations.

(3) Mobility test. A test to determine vehicle "speed-made-good" along a traverse consisting of two or more

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* U. S. Army Tank-Automotive Command, "The AMC '71 Mobility Model," Technical Report 11789 (LL 143), Jul 1973, Warren, Mich.

contiguous terrain or road units. Speed-made-good is computed by dividing the time required by a vehicle to complete a traverse into the straight-line distance between the beginning and end points of the traverse.

b. <u>Soil terms</u>

(1) <u>Unified Soil Classification System (USCS)</u>. A soil classification system based on identification of soils according to their textural and plasticity qualities and on their grouping with respect to their engineering behavior.

(2) <u>U. S. Department of Agriculture (USDA) Classification System</u>. A soil classification system developed by the United States Department of Agriculture based on identification of soils according to grain sizes or the relative proportions of the sand, silt, and clay fractions, each term being defined as a specific range of sizes.

(3) <u>Fine-grained soil</u>. A soil of which more than 50 percent (by weight) of the grains will pass a No. 200 U. S. standard sieve (grains smaller than 0.074 mm in diameter).

(4) <u>Coarse-grained soil</u>. A soil of which more than 50 percent (by weight) of the grains will be retained on a No. 200 sieve (grains larger than 0.074 mm in diameter).

(5) <u>Organic soil</u>. The living, dying, and dead vegetation that form a surface mat and the mixture of partially decomposed and disintegrated organic material (commonly known as peat or muck) below the surface mat. Small quantities of mineral soil may or may not be mixed with the organic material.

(6) Radforth Classification System. A widely used muskeg classification system first proposed by Dr. N. W. Radforth of Canada in 1952. The living vegetal cover is designated by a combination of capital letters, with each letter representing a particular botanical group and the letters listed in order of prominence of the particular group.

(7) Stamped "sand." Bedrock crushed or stamped to the texture and size of coarse-grained soils during copper mining operations and subsequently deposited hydraulically in depressions near the stamping mills.

c. Soil strength terms

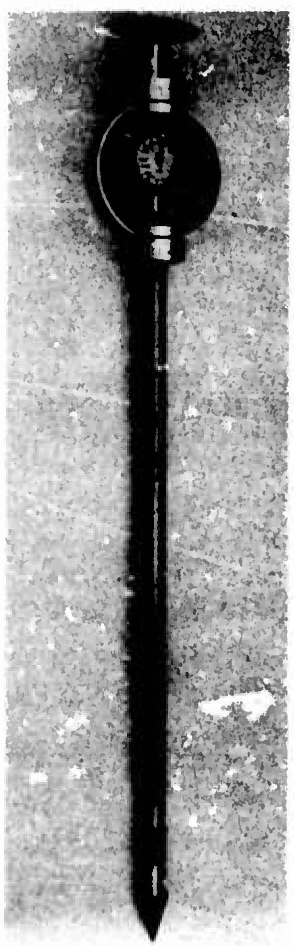


Fig. 1. Cone penetrometer

(1) Cone index (CI). An index of the shearing resistance of a medium obtained with a cone penetrometer (fig. 1). The value obtained represents the vertical resistance of the medium to penetration at 6 ft/min of a 30-deg cone of 0.5-sq-in.-base or projected area. The value, although usually considered dimensionless in trafficability studies, actually denotes pounds of force on the handle divided by the area of the cone base in square inches (i.e. pounds per square inch).

(2) Remolding index (RI). A ratio that expresses the proportion of the original strength of a soil that will be retained after traffic of a moving vehicle. The ratio is determined from cone index measurements made before and after remolding a 6-in.-long sample using the equipment shown in fig. 2. The test sample is obtained with a trafficability sampler (fig. 3).

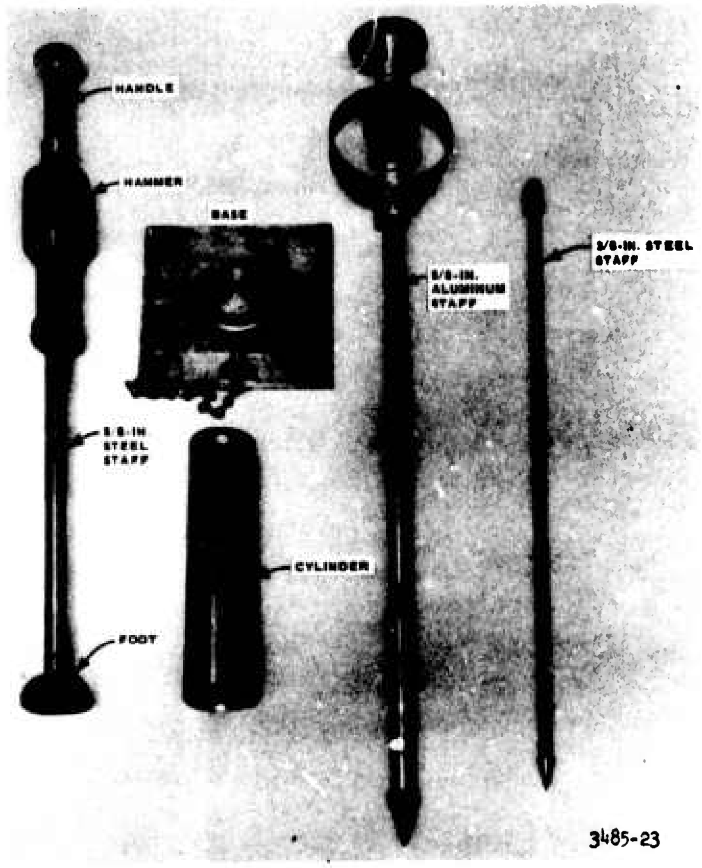


Fig. 2. Remolding equipment and cone penetrometer

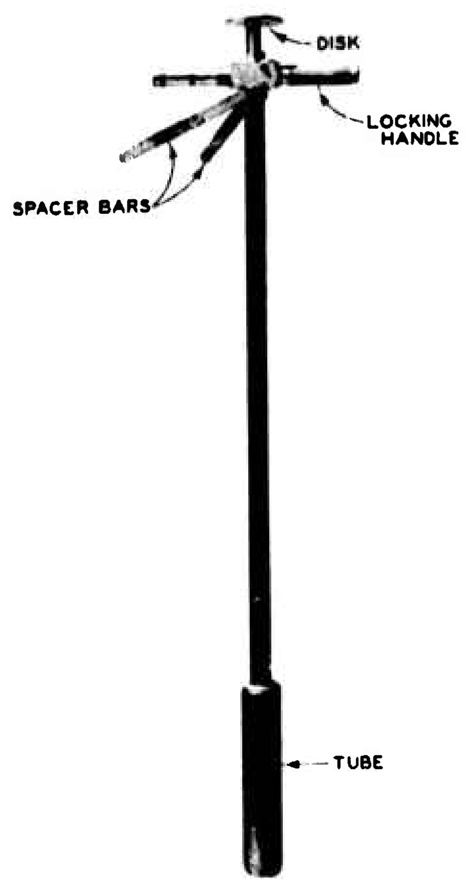


Fig. 3. Trafficability sampler

(3) Rating cone index (RCI). The product of the remolding index and the average of the measured in situ cone index for the same layer of soil. The index is valid only for fine-grained soils and sands with fines, poorly drained.

d. Terrain terms

(1) Terrain factor. Any attribute of the terrain that can adequately be described at any point (or instant of time) by a single measurable value; for example, slope or obstacle height.

(2) Terrain factor value. A specific occurrence of a terrain factor. For example, 2 percent is a factor value of the terrain factor slope.

(3) Terrain factor class (class range). A specified range of factor values established for a specific purpose; for example, a range of slope from 0 to 2 percent.

(4) Terrain factor class number. A number assigned to a terrain factor class range. For mobility purposes, terrain factor class numbers are assigned in order of increasing severity of effect on vehicle performance (fig. 4).

(5) Terrain factor complex number. A combination of two or more terrain factor class numbers chosen for a specific purpose.

(6) Terrain unit. A patch (areal) or length (linear) of terrain assumed to be homogeneous in terms of specific terrain factors and normally described by a specific array of terrain factor class numbers.

e. Vehicle terms

(1) Immobilization. The inability of a self-propelled vehicle to go forward or backward.

(2) Pass. One trip of a vehicle over a test course.

	Class Numbers													
Terrain Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Surface Type	Fine-Grained Soil	Coarse-Grained Soil	Muskeg											
Surface Strength (CI or RCI)	>280	221-280	161-220	101-160	61-100	41-60	33-40	26-32	17-25	11-16	0-10	13-25	7-12	0-6
Slope (%)	0-2	2.1-5	5.1-10	10.1-20	20.1-60	40.1-60	60.1-70	>70						
Obstacle Approach Angle (deg)	178.6-180	180-181.5	175.6-178.5	181.5-184.5	170.1-175.5	184.5-190	158.1-170	190.1-202	149.1-158	202.1-211	135.1-149	211.1-225	90.0-135	226-270
Obstacle Vertical Magnitude (in.)	0-6	6.1-10	10.1-14	14.1-18.0	18.1-23.6	23.7-33.5	>33.5							
Obstacle Base Width (in.)	>47	36.1-47	24.1-24	12.1-24	0-12									
Obstacle Length (ft)	0-1	1.1-3.3	3.4-6.6	6.7-10.0	10.1-19.9	20.0-492	>492							
Obstacle Spacing (ft)	>197.0	65.7-197.0	36.4-65.6	26.5-36.3	18.3-26.4	13.4-18.2	8.3-13.3	0-8.2						
Obstacle Spacing Type	Random	Linear												
Surface Roughness	0-0.4	0.5-1.5	2.6-3.5	3.6-4.5	4.6-5.5	5.6-6.5	6.6-7.5	> 7.6						
Stem Diameter (in.)	>0.1	>1.0	>2.4	>3.9	5.5	7.0	8.7	9.8						
Stem Spacing (ft)	>328	65.6-328	36.4-65.5	26.5-36.3	18.3-26.4	13.4-18.2	8.3-13.3	0-8.2						
Visibility (ft)	>164	79.0-164	39.6-78.9	29.8-39.5	20.0-29.7	15.1-19.9	10.1-15.0	5.1-10.0	0-5.0					

Fig. 4. Areal terrain factor class numbers

(3) Multiple passes. More than one trip of a vehicle in the same path over the test course.

(4) Mobility index. A dimensionless number that results from a consideration of certain vehicle characteristics. It is used to obtain an estimate of the vehicle cone index.

(5) Vehicle cone index (VCI). The minimum rating cone index (RCI) that will permit a vehicle to complete a specified number of passes; thus, VCI_{50} means the minimum RCI necessary to complete 50 passes, and VCI_1 means the minimum RCI necessary to complete one pass.

(6) Maximum drawbar pull. The maximum amount of sustained towing force a self-propelled vehicle can produce at its drawbar under given test conditions.

(7) Drawbar-pull coefficient at 20 percent slip (D/W_{20}). The amount of drawbar pull developed by a vehicle at 20 percent vehicle slip, expressed as a percentage of the vehicle test weight.

(8) Towed motion resistance. The amount of force required to tow a test vehicle in neutral gear under given test conditions.

(9) Slip. The percentage of track or wheel movement ineffective in thrusting a vehicle forward.

(10) Ride. The quality of vibratory motions caused by random terrain irregularities as sensed by a vehicle occupant.

(11) Absorbed power. The rate at which vibrational energy is absorbed by a vehicle occupant. It is a measure of ride quality.

f. Surface geometry terms

(1) Slope or macrogeometry. The angular deviation of a surface from the horizontal, expressed as a percentage.

(2) Surface roughness or microgeometry. Microvariations of the terrain surface that adversely affect vehicle ride dynamics.

(3) Root mean square (rms) elevation. A measure of surface roughness expressed as the root mean square deviation of the terrain amplitudes of a microsurface profile from the mean. (Because peculiarities occur in natural terrain microprofiles, special data handling techniques are used in preprocessing the profile data.)

g. Vegetation terms

(1) Stem diameter. The diameter of the tree stems at breast height (4.5 ft) above the ground.

(2) Stem spacing. The average distance between tree stems. This value is computed from the number of stems per unit area.

(3) Recognition distance or visibility. The distance at which a vehicle driver can see and recognize objects that may be hazardous to his vehicle or to himself.

PART II: TEST PROGRAM AT HOUGHTON, MICHIGAN

4. The test sites were located generally in the central portion of the Keweenaw Peninsula of upper Michigan, as shown in fig. 5. The area is representative of the wide variation in topography formed in resistant Pre-Cambrian bedrock and modified by Pleistocene glacial processes. The principal effect of this glaciation on topography was a leveling of the surface by the filling of depressions and the erosion of less resistant bedrock by glacial scour. Generally, the unweathered surface is flat to rolling with scattered knobs, kettles, minor ridges with relief of less than 75 ft, and pitted outwash plains. Glacial deposition types are mainly moraines, tills or ground moraines, outwashes, and glacio-lacustrine deposits. Most of the higher areas are parallel to the consequent drainage pattern that has developed along zones of weaker bedrock. The lower areas are filled with coarse and fine sands and silts of probable glacio-lacustrine origin. Principal soil types of the higher areas are of the Keweenaw-Munising-Kalkaska association (USDA classification) characterized by well-drained sandy loam glacial tills derived from reddish acid sandstones. The lower areas are of the Gay association of poorly drained soils in depressions with organic surface layers. Access is generally poor throughout the area because of heavy forest cover and a low stream gradient that produces widespread swampy conditions. A dense second growth of northern hardwoods, principally maple, birch, elm, poplar, ash, hemlock, and fir, covers most of the higher terrain. The poorly drained lower areas are characterized by swamps and organic bogs with high water tables. Heavy growth of moss and lichens covers most of the sandy open areas.

5. Precipitation is generally heavy, with yearly normals of 35 in. of rain and more than 100 in. of snow and sleet. Temperatures range from a mean of 10 F in January to a mean maximum of 73 F in July.

6. A majority of the inhabitants are scattered throughout small villages that sprang up around copper mining operations about 1900. Most of the land is still owned by either copper or lumber interests,

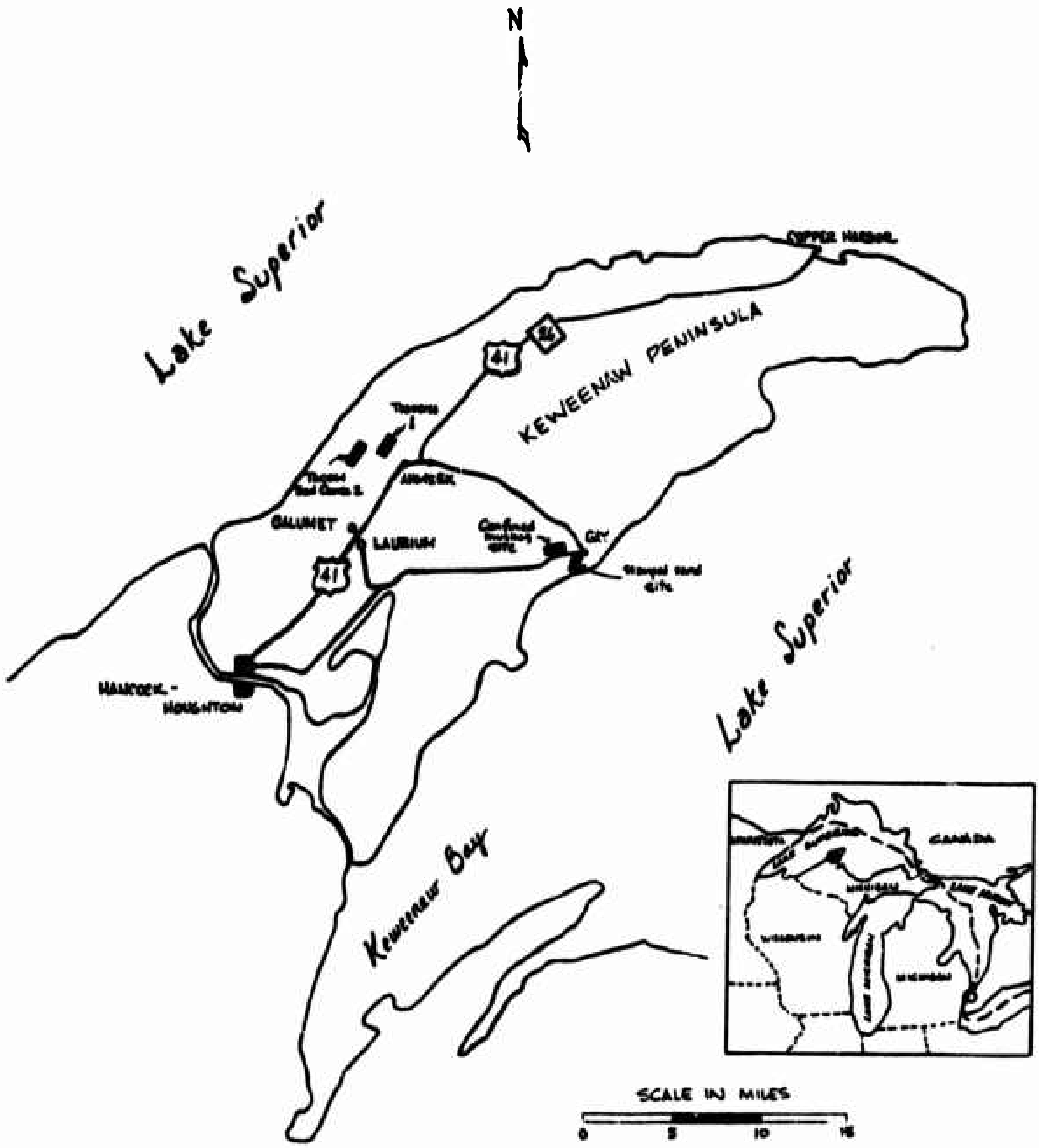


Fig. 5. Location of test sites in Upper Peninsula of Michigan

which purchased the area for its products. Copper operations are now only minimal, having peaked during World War II, but forestry and agriculture are still important. A major source of revenue is tourists, drawn to the area by its natural beauty, serenity, winter sports, and proximity to Isle Royale National Park.

Description of Test Sites

7. Three types of tests were conducted in the Houghton area: trail, cross-country, and special-terrain. One trail course (TACOM Trail Course 2) selected near Ahmeek (fig. 5) was composed of various combinations of slope, microgeometry, vegetation (bordering trail), and surface conditions. One cross-country traverse selected in the Ahmeek area was composed of various combinations of microgeometry, vegetation, and surface conditions. Two special terrains were used, one composed of organic soil (muskeg) and the other of crushed rock of the size and texture of coarse-grained sand (stamped sand); both were in the general vicinity of Gay, Michigan (fig. 5). The crushed rock is actually a large deposit of crushed mine tailings from copper mine operations at the old Mohawk Mill at Gay, subsequently deposited on the nearby Lake Superior shore.

TACOM Trail Course 2, Ahmeek, Michigan

8. Located 3 miles northwest of Ahmeek (see fig. 5), TACOM Trail Course 2 (fig. 6) had been used in the past by TACOM in vehicle trail tests. Initially, WES personnel surveyed the 15,000-ft course to obtain a ground-surface profile (fig. 7) to aid in terrain unit selection. After the profile was plotted, the trail course was divided into 18 distinct terrain units based on variations in surface geometry, strength, vegetation, slope, or linear features (such as streams). The trail was about 10 ft wide and ran through woody areas where trees bordered the trail, affecting vehicle performance, and through open areas. Dominant soil type is Kalhaska sand, which ranges from nearly pure sand to light, loamy sand in colors of gray and brown. The low fertility of this sand,

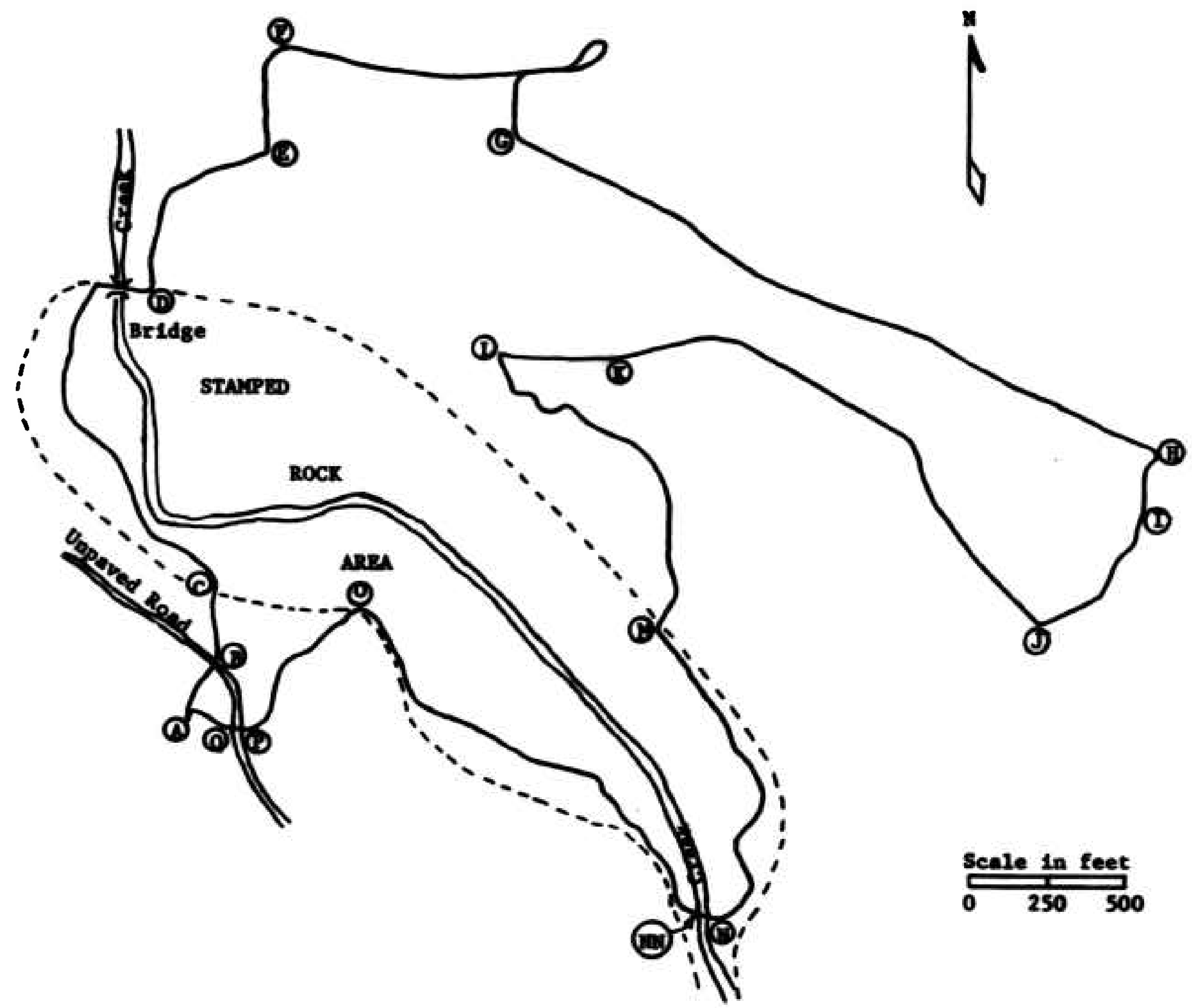
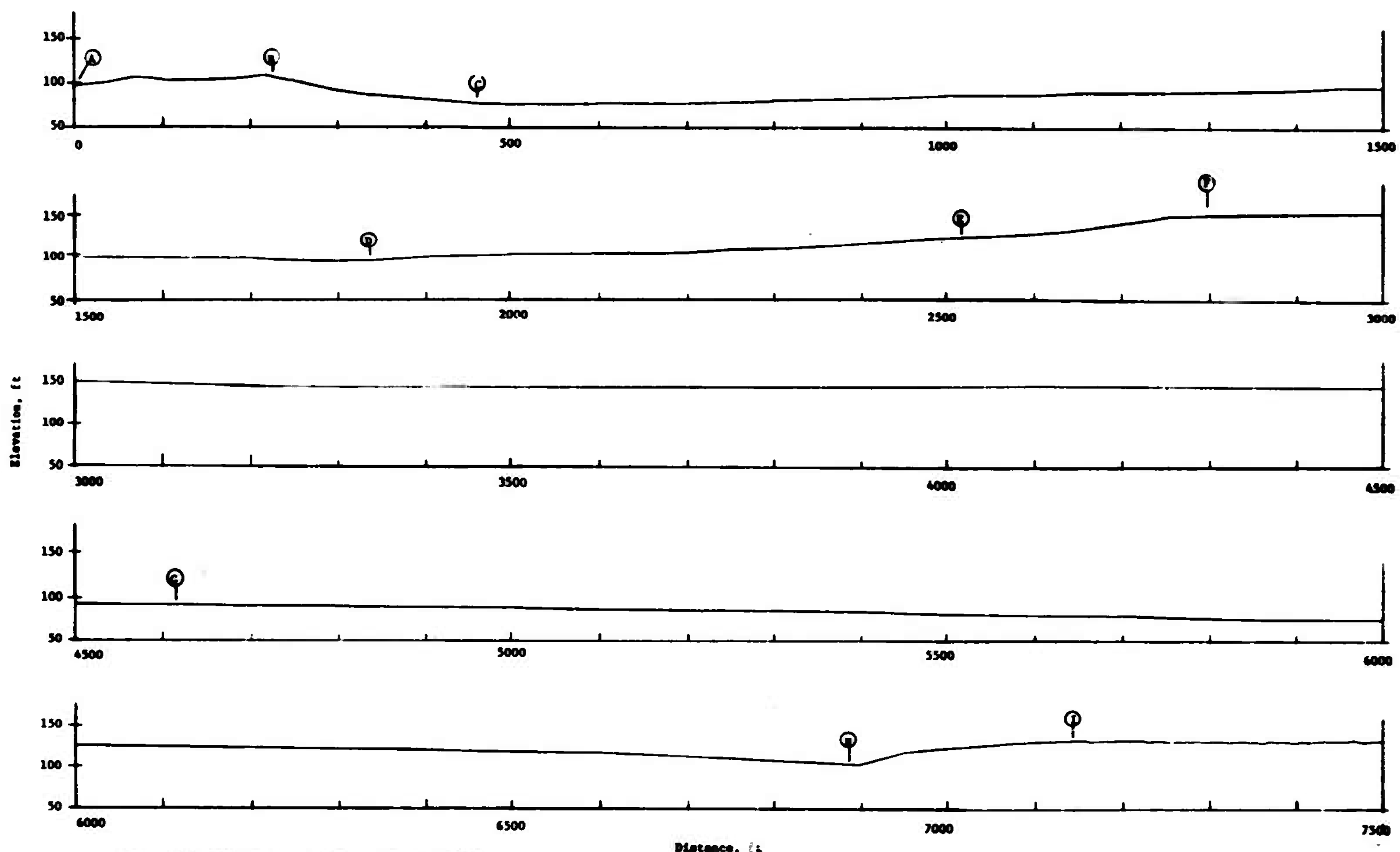


Fig. 6. Plan view, TACOM Trail Course 2, Houghton, Michigan



NOTE: Each trail unit is identified by the letter at its beginning, e.g. unit A-B is designated Trail Unit A.

Fig. 7. Surface profile, TACOM Trail Course 2, Houghton, Michigan, 1/2 in. = 100 ft (Continued)

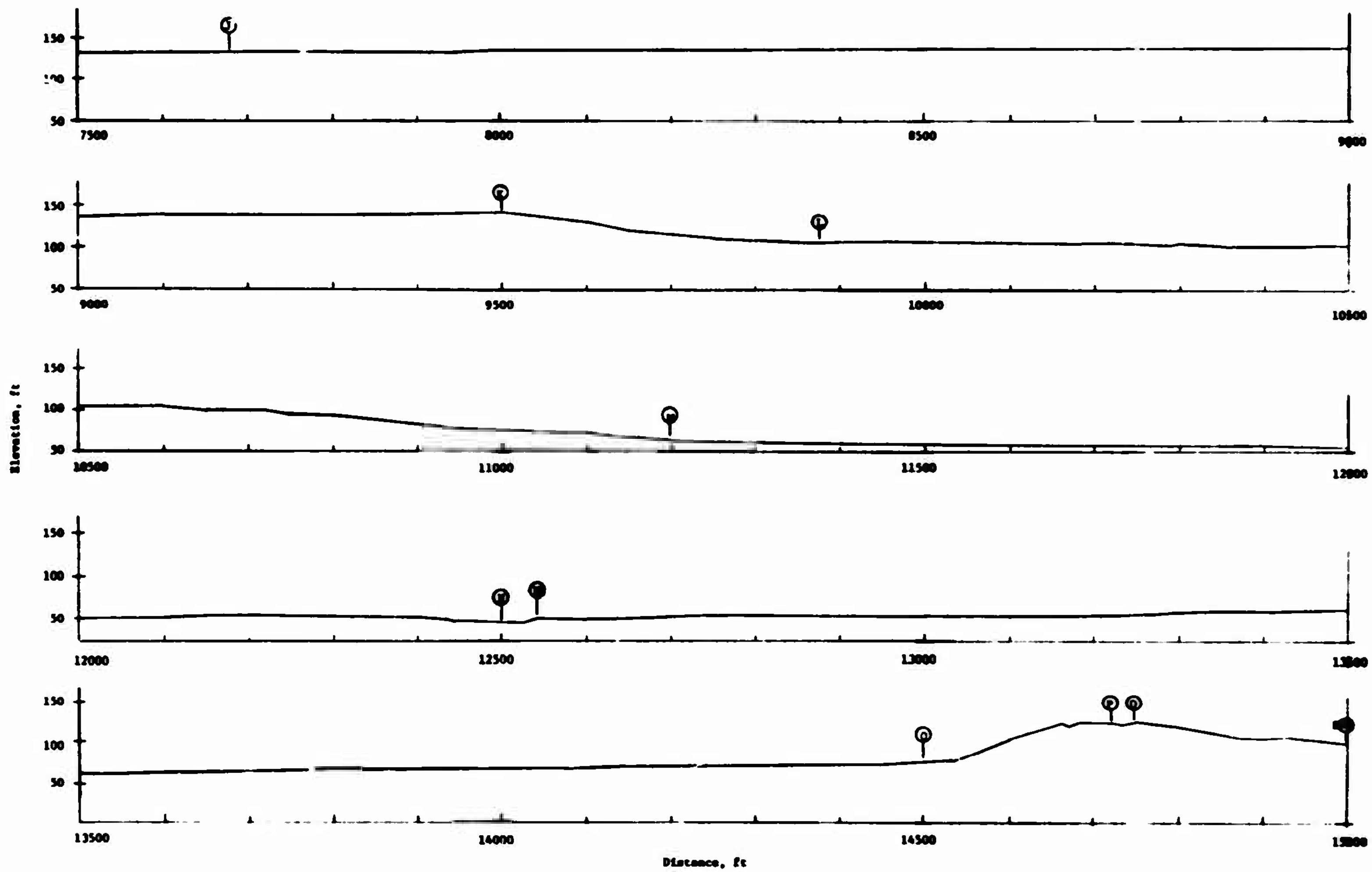


Fig. 7. (Concluded)

combined with the relatively dense crown growths of maples and pines, allows only limited ground-cover growth. Therefore, most of the trail areas are relatively barren, except in the woody areas where ground litter obscures the sand surface or rocks cover the trail surface. On portions of the course, the trail crosses areas of stamped, coarse-sand-size rock remaining from the copper mining operations in the area. These areas are relatively barren, with sand colors ranging from gray to pink depending on the parent bedrock from which they were stamped. The stamped areas on this course are also littered with logs and stumps from logging operations in the area. One fordable creek and several bisecting, sandy tertiary roads intersect the trail at several points.

9. The wide variety of terrain factors affecting vehicle performance, along with their varying effects on tracked and wheeled systems, combined to create a useful test of these systems in the various environmental conditions on this course. Terrain data collection methods used for this report followed techniques described in detail for computer input to the AMC-71 Ground Mobility Model.* The various terrain descriptors were collected and summarized in the form of table 1.

Traverse 1, Ahmeek, Michigan

10. Traverse 1, located 1 mile northwest of Ahmeek (fig. 5), was short (2346 ft in length) and rough. The entire area is harshly glaciated with random rounded and traverse ridges and abrupt irregular ditches. The main soil type is gray Kalhaska sand with some loam mixed. There were three terrain units in this traverse. The first was 550 ft long, relatively rough and open with lichens and grasses for surface cover. The second was 750 ft of gradually rolling terrain, with a 3-ft-high, 200-ft-diam shrub-covered knoll the dominant surface feature. The small shrubs hindered visibility slightly and increased the maneuvering required to traverse the unit. Lichens, grasses, and scattered blueberry patches interspersed in the rocky, sandy soil provided surface cover. The third unit comprised the last 1046 ft of the traverse.

* *Ibid.*, page 2.

It was an extremely rough, open area of lichens, grasses, scattered shrubs, stumps, and blueberry patches, and was the roughest unit of the three with respect to surface geometry.

11. The environmental factor that limited vehicle speed over the entire traverse was surface roughness. The few shrubs and stumps required some vehicle maneuvering, but the vehicle speeds were definitely limited by ride quality.

Confined muskeg site, Gay, Michigan

12. The confined muskeg site was 1 mile west of Gay, Michigan (fig. 5), and 2 miles northwest of the other test site at Gay. The area was composed of nonwoody vegetation and grass (classified FI by the Radforth Classification System) with some widely scattered scrub trees. Organic material in the area varies from 6 to 13 ft deep.

Stamped-sand site, Gay, Michigan

13. Located 1 mile south of Gay, Michigan (fig. 5), the stamped-sand site is dry and barren and composed of gray, stamped rock of the size and texture of coarse sand, a by-product of the copper industry in the area. The gray color is derived from the parent bedrock stamped to coarse-sand size in copper mining operations. These mine tailings were hydraulically deposited on the Lake Superior shore by the old Mohawk Mill at Gay. This coarse-sand area was used for slope tests. Littoral drift had separated the finer particles and deposited them southwest of their original deposition. This fine-sand area was used for maximum-drawbar-pull, towed-motion-resistance, and speed tests.

Test Vehicles

14. Vehicle characteristics of the Wheel/Track Convertible Test Rig are presented in fig. 8; various views of the Test Rig in both the wheeled and the tracked mode are shown in fig. 9. Vehicles used for comparisons in the test program (fig. 10) were those that were readily available and could accommodate cross-country payloads of 1/4-5/4 tons.

Vehicle Characteristics - Wheel/Track Test Rig

Engine - 289-cu-in. Ford, V8, water-cooled, gasoline

Transmission - Ford 3-speed automatic

Cross drive - Bowen DS-50

Suspension - Independent, torsilastic

Gross Weight (wheeled mode) - 5600 lb

Gross Weight (tracked mode) - 6700 lb

Tires - Goodyear, Terra, 26X12-12, chevron grip

Track width - 15.25 in.

Clearance - 14 in.

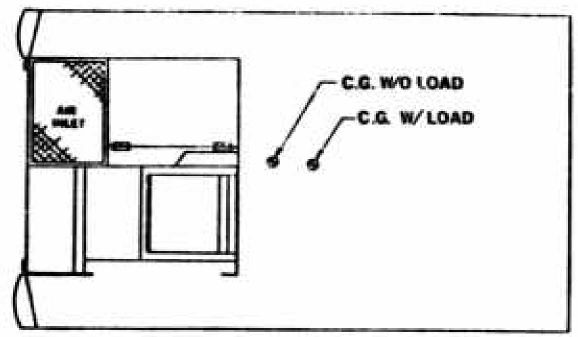
Flotation - 2.6-in. freeboard to deck

Speed range - 0-40 mph (offroad)

Vehicle cone index - 11, wheeled; 9, tracked

Ground contact pressure - 8.9 psi, wheeled; 3.4 psi, tracked

(Roll bars added to vehicle as safety precaution are not shown.)



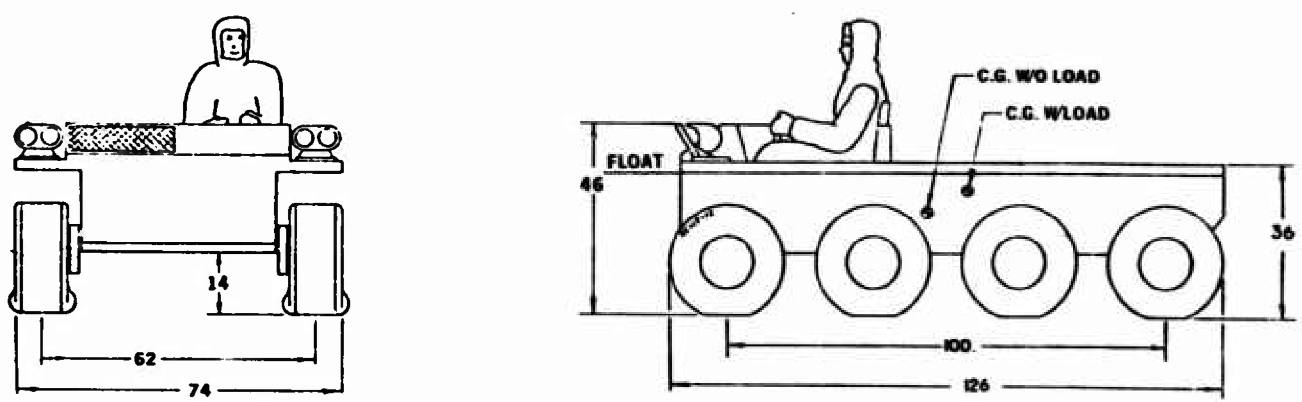
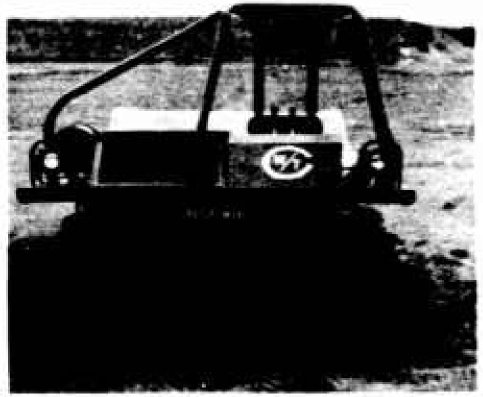


Fig. 8. Wheel/Track Convertible Test Rig

a. Wheeled

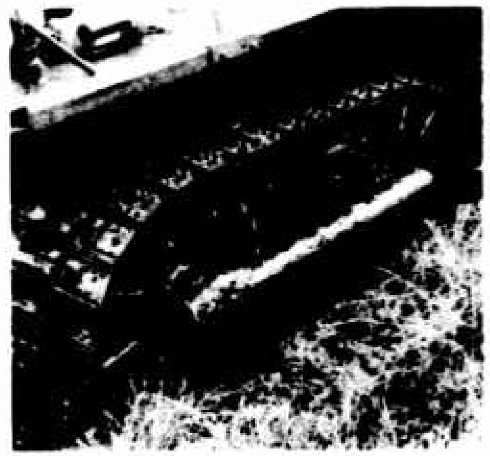


b. Wheeled

c. Wheeled

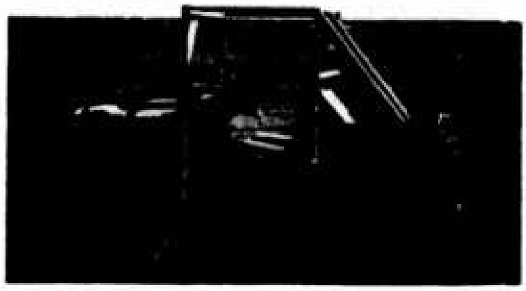
d. Wheeled

e. Tracked

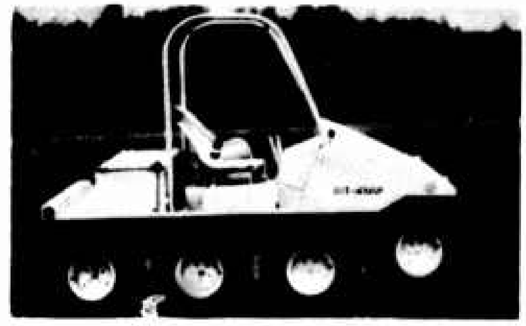


f. Tracked

Fig. 9. Wheel/Track Convertible Test Rig

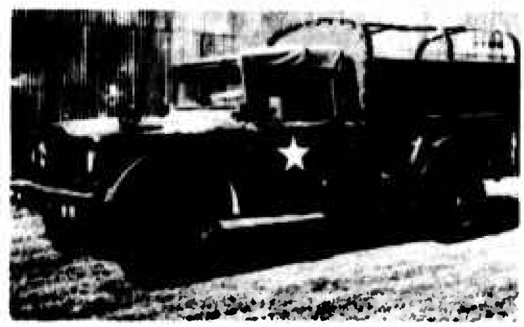


a. M151A2



b. Wolverine

c. M274A2



d. M715

e. M29C

f. M104

Fig. 10. Comparison test vehicles

Tabulated below are the gross test weights, cross-country payloads, and tire pressures (or track widths) of all the vehicles.

Vehicles	Gross Test Weight, lb	Cross Country Payload lb	Tire Pressure, psi, or Track Width, in.
		Wheeled	
Wheel/Track	5600	1500	4-5
M151A2	3200	500	12 front; 18 rear
Wolverine (Commercial)	3160	1000	5
M274A2	2100	1000	12
M715	6000	2500	35
		Tracked	
Wheel/Track	6700	1500	15.25
M29C	5700	1200	20
M104 (without gun)*	5760	500	15.5

* Tested empty.

Unavailability, generally the result of mechanical breakdowns, precluded testing all vehicles on all test courses or slopes. Two versions of the Wheel/Track Test Rig in the wheeled mode were tested at Gay, Michigan. The original version was powered by a 141-cu-in. jeep engine, but early tests indicated insufficient power and speed output. Therefore, when this version developed mechanical difficulties, a more powerful 289-cu-in. engine was installed for the remainder of the test program.

Tests Conducted, Procedures, and Data Collected

15. Trail and cross-country tests were conducted to obtain average speeds in a variety of individual trail and terrain (off-road) units, as well as average speed over a traverse consisting of a group of

contiguous trail and terrain units. Tests were also conducted in special-terrain units to acquire data necessary to develop pertinent terrain-vehicle relations or to observe, in special-terrain conditions, behavior at the wheel-track interface. Tests were also run to observe ride and handling characteristics of the Test Rig.

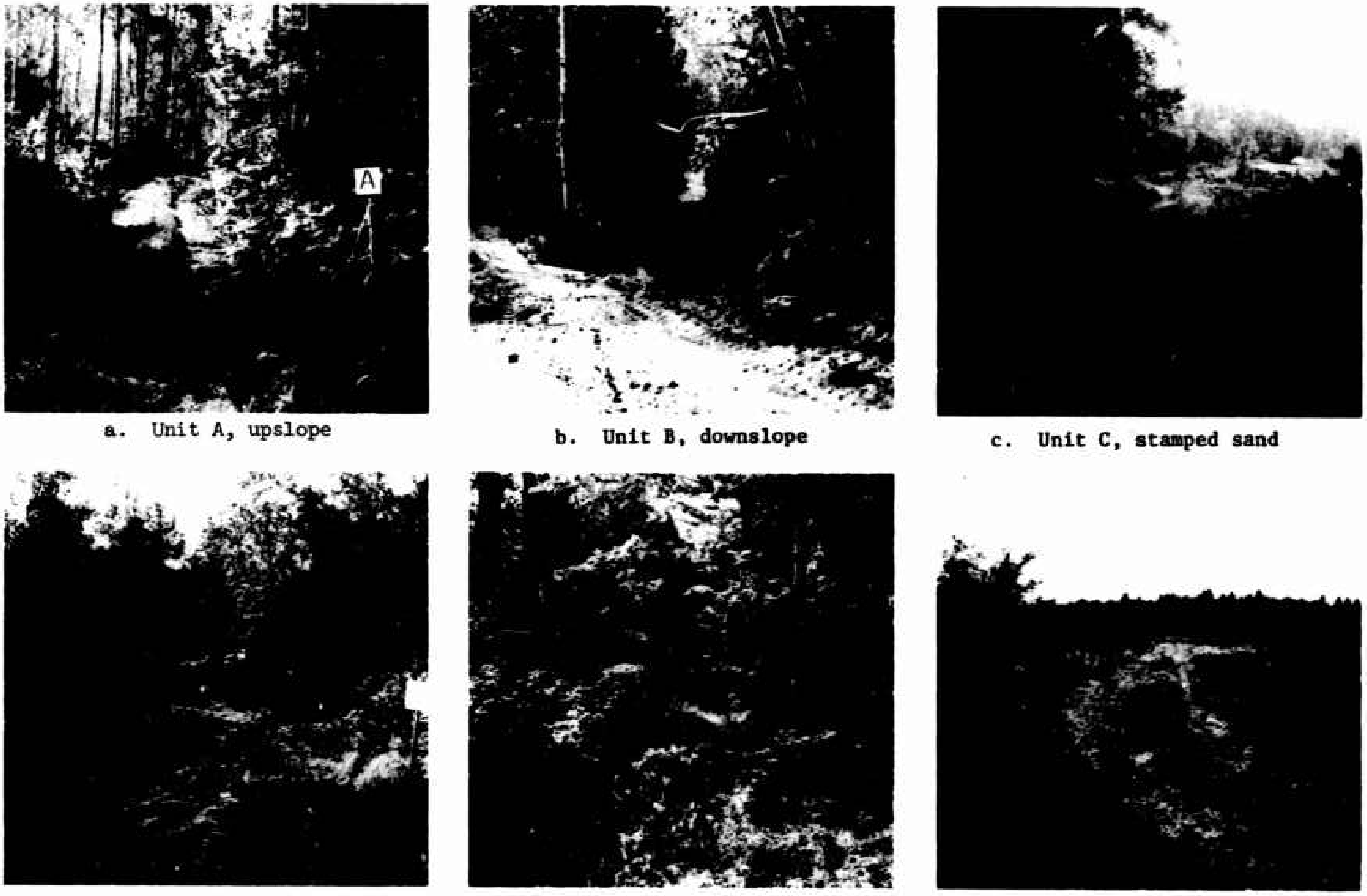
Trail tests

16. A driver experienced in trail and cross-country testing was selected to drive all test vehicles during all test phases. Each vehicle was driven over the trail course (see fig. 11) at a speed considered by the driver to be the maximum safe speed for that test vehicle based on the limitations imposed by the terrain conditions encountered. The vehicles were timed with a stopwatch through each unit on the trail course. Using these times, speeds were calculated for each vehicle in each trail unit over previously measured distances. All vehicles negotiated the complete 15,000-ft course in clockwise and counterclockwise directions to permit analysis of the directional effects of slopes, microgeometry, vegetation, etc., on vehicle performance. Results of these tests are shown in table 2. The Wheel/Track Test Rig in the tracked mode is not included in this table because mechanical problems forced suspension of tests with the tracked rig before trail-course testing was conducted.

17. The average speed of each vehicle is shown at the bottom of table 2. In all vehicle tests, especially those with the Wheel/Track Test Rig, an observer-rider accompanied the driver on each test to obtain information on vehicle-driver response to various vehicle-terrain conditions. Information obtained for the main vehicle of interest, the Wheel/Track Test Rig, during these tests is shown in table 3. Figs. 6 and 7 can be used in conjunction with table 2 to analyze fully the performance of the Test Rig on this trail course.

Traverse tests

18. All the test vehicles were timed with a stopwatch through each of the three terrain units of Traverse 1. Average speeds were calculated for each vehicle in each terrain unit and are shown in table 4.



a. Unit A, upslope

b. Unit B, downslope

c. Unit C, stamped sand

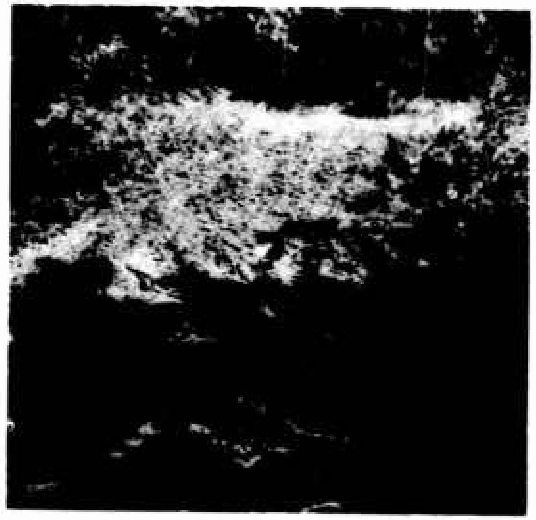
d. Unit D, upslope

e. Unit E, upslope

f. Unit F, open, flat, grassy area

Fig. 11. TACOM Trail Course 2, trail units (1 of 3 sheets)

g. Unit G, narrow trail in heavy woods

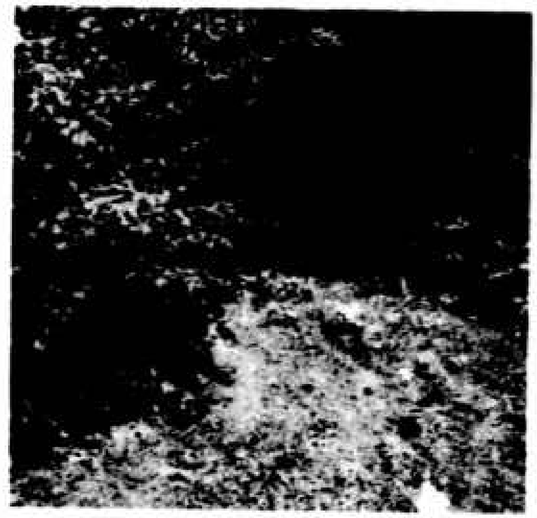


h. Unit H, upslope

Unit I, surface roughness unit

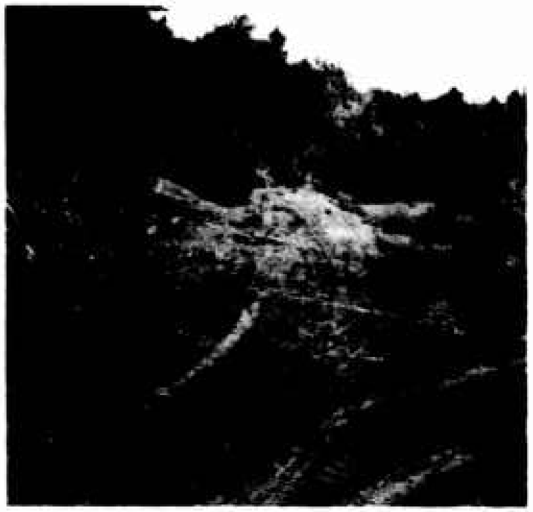
j. Unit J, open trail

k. Unit K, downslope



l. Unit L, narrow trail in heavy woods

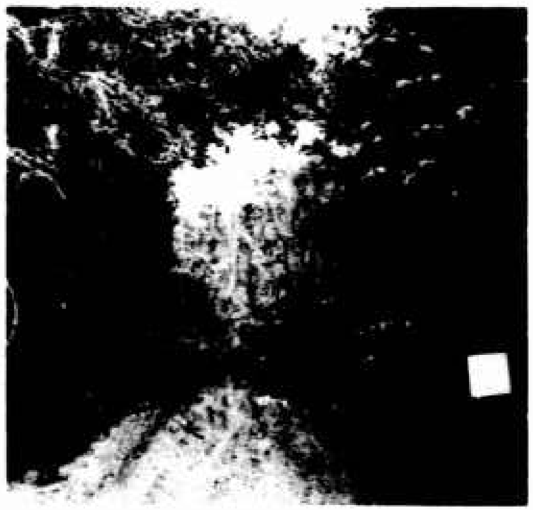
Fig. 11. (2 of 3 sheets)



m. Unit M, stamped sand

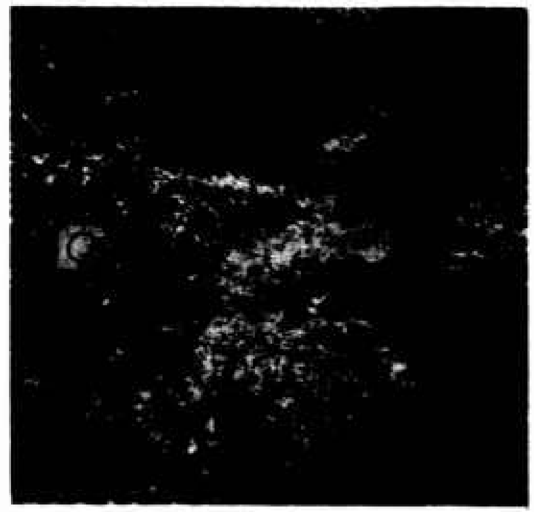
n. Unit N, stream crossing

o. Unit NN, stamped sand



p. Unit O, 32.3 % upslope

q. Unit P, road crossing



r. Unit Q, downslope to A

Fig. 11. (3 of 3 sheets)

Pertinent terrain data are described in table 5. Notes and observations of the rider-observer during the traverse tests with the Wheel/Track Test Rig in both wheeled and tracked modes are given in table 6.

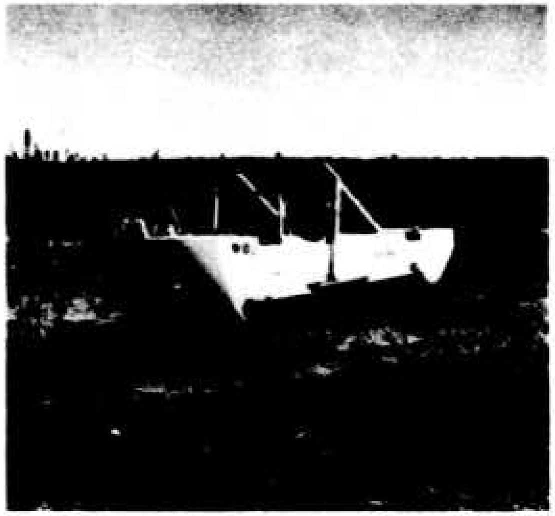
Special-terrain tests

19. Confined muskeg tests. Trafficability tests were conducted in an organic muskeg (see fig. 12) at Gay, Michigan, with the Test Rig in both wheeled and tracked modes and with one wheeled vehicle (Wolverine) for comparison. Plans called for testing with one tracked vehicle (M29C) also, but trafficability testing with the M29C was deleted from the program because past experience with it indicated that it could make 50 passes with ease in this area. The vehicles were driven forward and backward on a straight 100-ft lane until immobilization occurred, or the required 50 passes were completed. Pertinent soil data and test notes were taken for each test; results are shown in table 7.

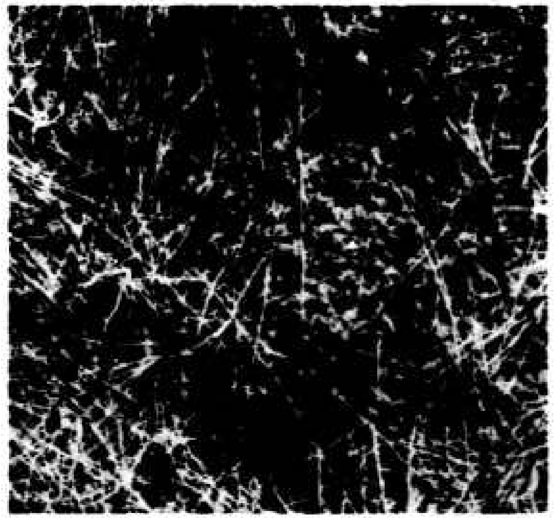
20. Several general maneuvering and handling tests were conducted in the muskeg site with the Wheel/Track Test Rig in both modes, the Wolverine, and the M29C to obtain information for comparing performance of the three vehicles. In these tests the driver maneuvered each vehicle through a lightly forested muskeg area to determine vehicle response to the sharp turns required to maneuver around trees and maintain a constant speed in the organic terrain. In the more open area used for the trafficability tests, the driver completed the tightest turning circle possible with each vehicle as determined by the terrain conditions. Results of these maneuvers will be discussed later in this report (see paragraph 47).

21. Stamped-sand tests. The stamped-sand site (see fig. 12) at Gay, Michigan, was divided into two general test areas by texture and grain size, fine stamped rock and coarse stamped rock. Measurements of maximum speed, maximum sustained drawbar pull, and average towed motion resistance were obtained for each vehicle tested in the fine-stamped-sand area (CI = 110). Slope-negotiability and speed-on-slope tests were conducted in the coarse-tailings area.

a. Areal view, muskeg area

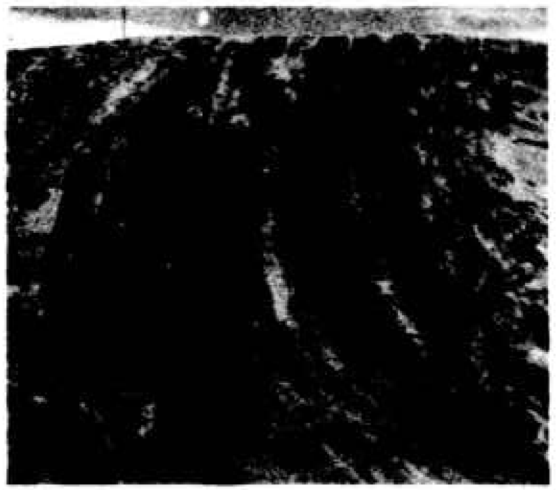


b. General view muskeg area



c. Closeup, muskeg area

d. Areal view, stamped sand slopes



e. General view, stamped sand slope

f. Wheeled vehicle slope

Fig. 12. Special-terrain tests

22. In the fine stamped-sand area, a 200-ft-long timing lane was marked off in a relatively open area with ample acceleration distance at each end for maximum speed tests with the vehicles. The test lane ran north to south parallel to the Lake Superior shoreline. A 15-mph wind from the south and a southerly downslope of 1 percent required tests in both directions through the timing lane to obtain average speeds uninfluenced by these factors. Test results are shown in table 8.

23. Drawbar-pull tests were conducted parallel to the speed test lane. The maximum sustained drawbar pull developed by each vehicle in low gear was measured with a hydraulic load cell. The load applied to the vehicle was gradually increased until the vehicle developed a maximum sustained drawbar pull as indicated by the load cell. This sustained pull was usually developed at high track or wheel slip (near 100 percent). Upon completion of drawbar-pull tests, the test vehicles were towed at 2 mph, and the average motion resistance of the vehicle in the stamped sand was obtained with a hydraulic load cell. Results of these tests also are shown in table 8.

24. The coarse-stamped-sand area was used for slope-negotiability and speed-on-slope tests. Preliminary testing indicated slopes in excess of 15 percent would be necessary to seriously influence vehicle performance. Therefore, tests were conducted on slopes ranging from 15.3 to 58 percent. The slopes were smoothed before each vehicle test by dragging two large timbers behind a support vehicle. Pertinent slope and soils data were collected as shown in the tabulation below.

Slope No.	Slope, %	Slope Length, ft	Cone Index 0- to 6-in.
1	15.3	90	208
2	23.8	50	90
3	27.6	85	202
4	33.6	35	91
5	38.8	35	54
6	46.0	30	44
7	54.0	30	71
8	58.0	30	59

Each vehicle was placed in a starting position on level ground with the front of the vehicle at the toe of the slope. The vehicle was accelerated upslope through a timing zone to obtain data on the effects of slope on vehicle speed. Vehicle performance in terms of speed was obtained with a stopwatch to determine the speed on each slope. Slopes of increasing magnitude were used for each vehicle until an immobilization occurred. In all tests several runs were conducted with each vehicle in a range of gear combinations to obtain an optimum combination for maximum speed-on-slope. The best speed on each slope (unless noted) is included, together with pertinent test notes, in table 9.

PART III: TEST PROGRAM AT VICKSBURG, MISSISSIPPI

25. Two general areas were selected for special-terrain tests at Vicksburg: an area 16 miles north of Vicksburg near an old Mississippi River bend, now known as Albemarle Lake, and the reservation area of the WES. Three test sites were selected near Albemarle Lake (fig. 13): a soft alluvial buckshot clay area, grassy clay slopes, and a firm buckshot clay area nearby, known as Parker's Farm. Two sites were used at the WES: grassy silt slopes and a facility containing prepared test pits of clay (CH) and sand (SP) (USCS classification).

Description of Test Sites

Albemarle Lake Area

26. Wooded clay site. Albemarle Lake is a small oxbow located on the Louisiana-Mississippi border northwest of Vicksburg, Mississippi. The water level in the lake rises and falls with that of the Mississippi River, which feeds the lake. At the time of this test program, the river stage was low, and a wide expanse of wooded lakeshore was exposed and accessible. A gradual decrease in soil moisture content with increase in distance from the water's edge permitted testing on a range of soil strengths in a small area. Likewise, the water table varied from the surface near the water's edge to a few inches below the surface near the high bank. Willow trees with trunks ranging in diameter from 8 to 16 in. grow at the test site on a 10- to 12-ft average spacing.

27. Clay slopes. Two grassy clay slopes on the high bank above the wooded area were used for testing. One was a natural slope and the other was the end of a spur levee constructed at a time when the main stream of the Mississippi River passed near the test area. Both slopes were completely covered with Bermuda grass 4 to 6 in. high.

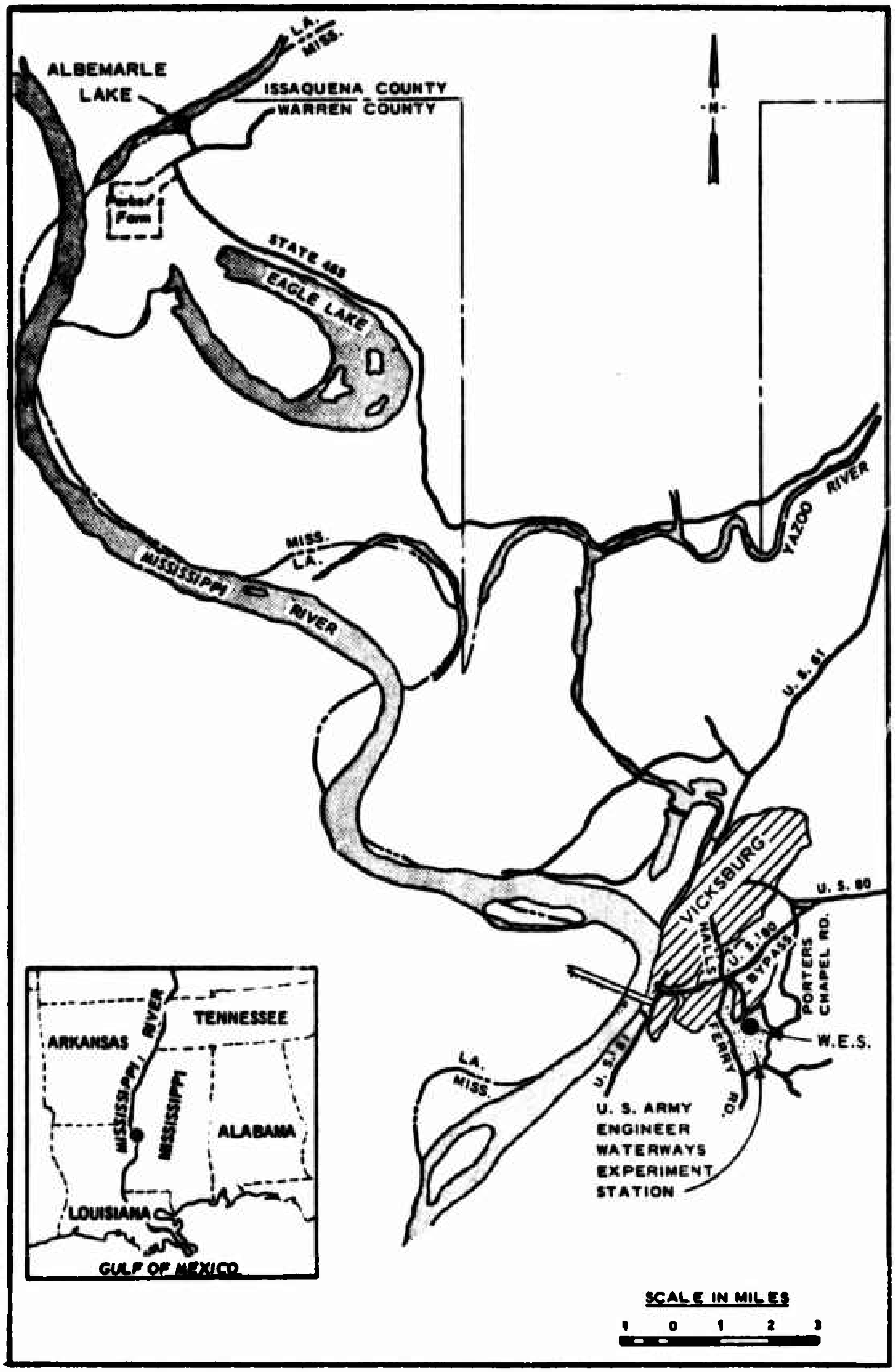


Fig. 13. Location of test areas, Vicksburg, Mississippi

28. Parker's Farm. Three firm buckshot clay courses completely covered with 6-in.-high Bermuda grass were selected at Parker's Farm (fig. 13) for determination of vehicle dynamic responses at various speeds over three degrees of surface roughness. The courses were selected based on availability and, therefore, were not variable enough to obtain a complete set of surface roughness-speed data for both wheeled and tracked versions of the Wheel/Track Test Rig.

WES reservation

29. Grassy silt slopes. Three steep silt slopes on the WES grounds were used for longitudinal speed-on-slope tests and side-slope tests (operation across the slope face) with the Test Rig. The slope embankments were created during construction of a roadbed bridging a deep ravine. They are completely covered with Bermuda grass, which had been mowed before the tests to about 2 in. high.

30. Laboratory clay and sand pits. Two prepared buckshot clay (CH) pits and one prepared sand (SP) pit were used for drawbar-pull and towed-motion-resistance tests. The clay pits were prepared to achieve two soil strengths, one approximately half the strength of the other. The sand pit was densified, pure, dry mortar sand.

Test Vehicles

31. Of the vehicles tested at Houghton, only the Wolverine and the Wheel/Track Test Rig were tested at Vicksburg. An M151 at the same cross-country payload replaced the M151A2 tested at Houghton. The Test Rig was tested as an 8x8 vehicle in both wheeled and tracked modes, and as an 8x4 in the tracked mode as time permitted.

Tests Conducted, Procedures, and Data Collected

32. Time restrictions placed on the test program after the Houghton tests resulted in minimum testing at Vicksburg, with emphasis on testing the Wheel/Track Test Rig in soft soil and in the laboratory.

Maneuvering and handling tests, therefore, were conducted in soft soil with the Test Rig to observe wheel-track interaction at their interface, as well as general performance while the vehicle was operating in soft, adhesive buckshot clay, which coated the entire vehicle running gear. Several tests were also conducted on grassy clay and silt slopes to compare Test Rig speeds with those of the other vehicles and to gain insight into vehicle "go-no go" slope-climbing ability. Drawbar-pull and towed-motion-resistance tests were conducted with the Test Rig on laboratory-prepared clay (CH) and sand (SP). No Wolverine drawbar-pull tests were conducted; results of previously conducted tests with the M151 and the M29C were used for comparison purposes. Preliminary tests were also conducted for determination of vehicle performance during surface roughness tests.

Albemarle Lake tests

33. Wooded, clay sites. General maneuvering and handling tests were conducted with the Test Rig in both wheeled and tracked modes in the wooded, alluvial soft clay area at Albemarle Lake. Areas were selected in the willows with sufficient spacing between trees to permit mounting of a high-speed camera on the vehicle to photograph mud accumulation on the running gear and possible slip at the wheel/track interface. The mounting bracket and camera added 3 ft to the required lateral clearance for vehicle passage. Consequently, areas were selected that afforded sufficient lateral clearance for vehicle and camera passage. Areas were selected to obtain a range of soil strengths, beginning at the water's edge and moving landward. Three areas were used based on the 0- to 6-in. RCI of each area: 11 RCI at the water's edge, 14 RCI at 75 ft landward of the water's edge, and 24 RCI near the high bank some 200-250 ft from the water's edge. Soil data for the 0- to 6-in. soil layer are shown below.

Area	CI	RI	RCI	Moisture Content, %	Dry Density, lb/ft^3
1	16	0.70	11	148.1	32.7
2	20	0.70	14	125.4	36.6
3	38	0.64	24	105.2	35.2

In each test area the driver switched on the high speed camera prior to the test and began maneuvering through the designated test lane. Maneuvering around the willows continued until the supply of film was exhausted in the camera (about 1-1/2 minutes). Appropriate test notes including driver comments on vehicle performance, estimates of mud buildup, and observations of handling characteristics were recorded for tests in each area.

34. Clay slopes. Two grassy clay slopes as described below were selected for speed-on-slope and side-slope tests.

Slope No.	Slope, %	Slope Length, ft	Cone Index
1	25	75	149
2 (levee)	35	75	417

In the speed tests each vehicle was accelerated upslope from a starting position at the toe of the slope through a 75-ft timing lane in the optimum gear/gear range configuration for maximum speed upslope. Speeds were calculated with a stopwatch and are shown in table 10. As indicated, the vehicles slipped slightly at the toe of slope 1, which was a high bank rising from the Albemarle Lake shore area and was slightly soft. Note that the tracked test rig was not tested on these slopes. The drive shafts of the Test Rig with tracks installed are more susceptible to shear on firm areas, especially in maneuvering, because of the increased traction obtained with the tracks. The low-pressure Terra-tires, which deflect substantially during maneuvering, remove some of the rigidity of the drive system that must remain on a more restrained setup, such as the tracked version. Therefore, no speed tests were attempted with the tracked version.

35. Upon completion of longitudinal slope tests, the tracked Test Rig was operated across the face of the slopes to observe the effect of side loadings on the vehicle running gear. Photographic coverage of vehicle operation at angles to the face of the slope was used, along with visual observation of vehicle performance, to analyze vehicle running gear performance under stresses induced by side loadings. At no time, however, did slip occur at the wheel-track interface.

36. Parker's Farm. The wheeled and tracked versions of the Wheel/Track Test Rig were driven at various speeds over three dynamics courses with surface roughness levels of 0.67, 1.44, and 1.49 in. (rms elevations), respectively. Only two days were allotted for these tests. Limited data obtained from instrumentation of the vehicle for dynamic responses were used to construct preliminary curves of surface roughness at the 6-watt level versus vehicle speed, as shown in figs. 14-16.

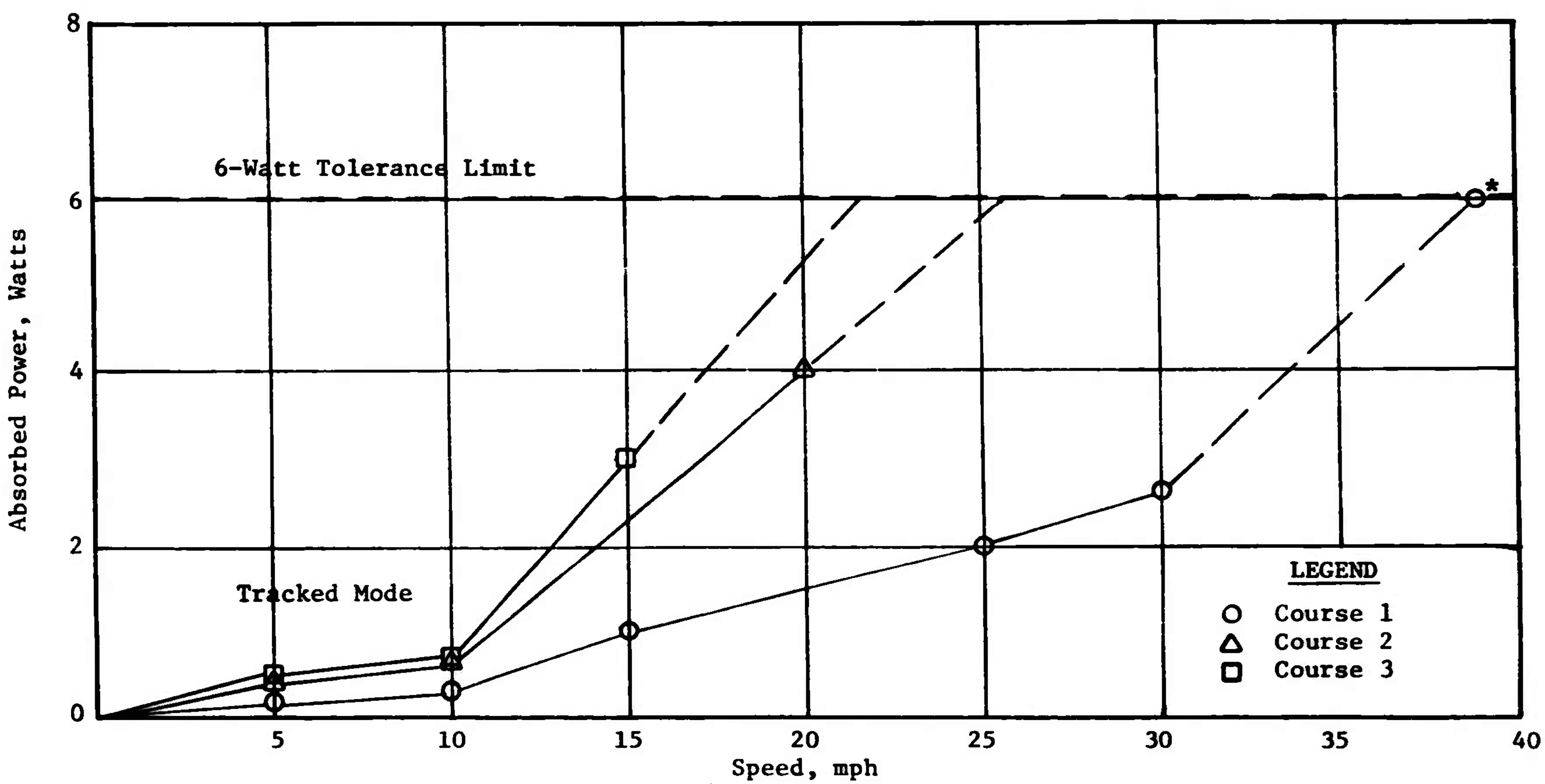
WES tests

37. Slopes. Three steep, grassy silt slopes, as described below, were used for slope tests on the WES reservation.

Slope No.	Slope, %	Slope Length, ft	Cone Index
3	40.3	35	451
4	44.2	35	368
5	53.5	50	368

Speeds-on-slopes were determined as described in paragraph 34, and are shown in table 10. Slopes of more than 53.5 percent were not available to conclusively determine the "go-no go" point for the vehicles on grassy silt.

38. Laboratory. Five drawbar-pull and towed-motion-resistance tests were conducted in the laboratory at WES with the Wheel/Track Test Rig in wheeled and tracked modes in 8x8 and 8x4 configurations. The wheeled and tracked versions were tested in an all-wheel-drive 8x8 configuration. The drive gear to the first and third road arms on each side of the tracked Test Rig was removed, and tests were conducted



* Low frequency wavelengths becoming significant at 30 mph; would most likely reach 6 watts at some slightly higher speed. Estimate could not exceed 40 mph. Tests stopped at 30 mph to preclude possible structural damage.

Fig. 14. Absorbed power versus speed, Wheel/Track Convertible, Parker's Farm, Vicksburg, Mississippi, preliminary test results

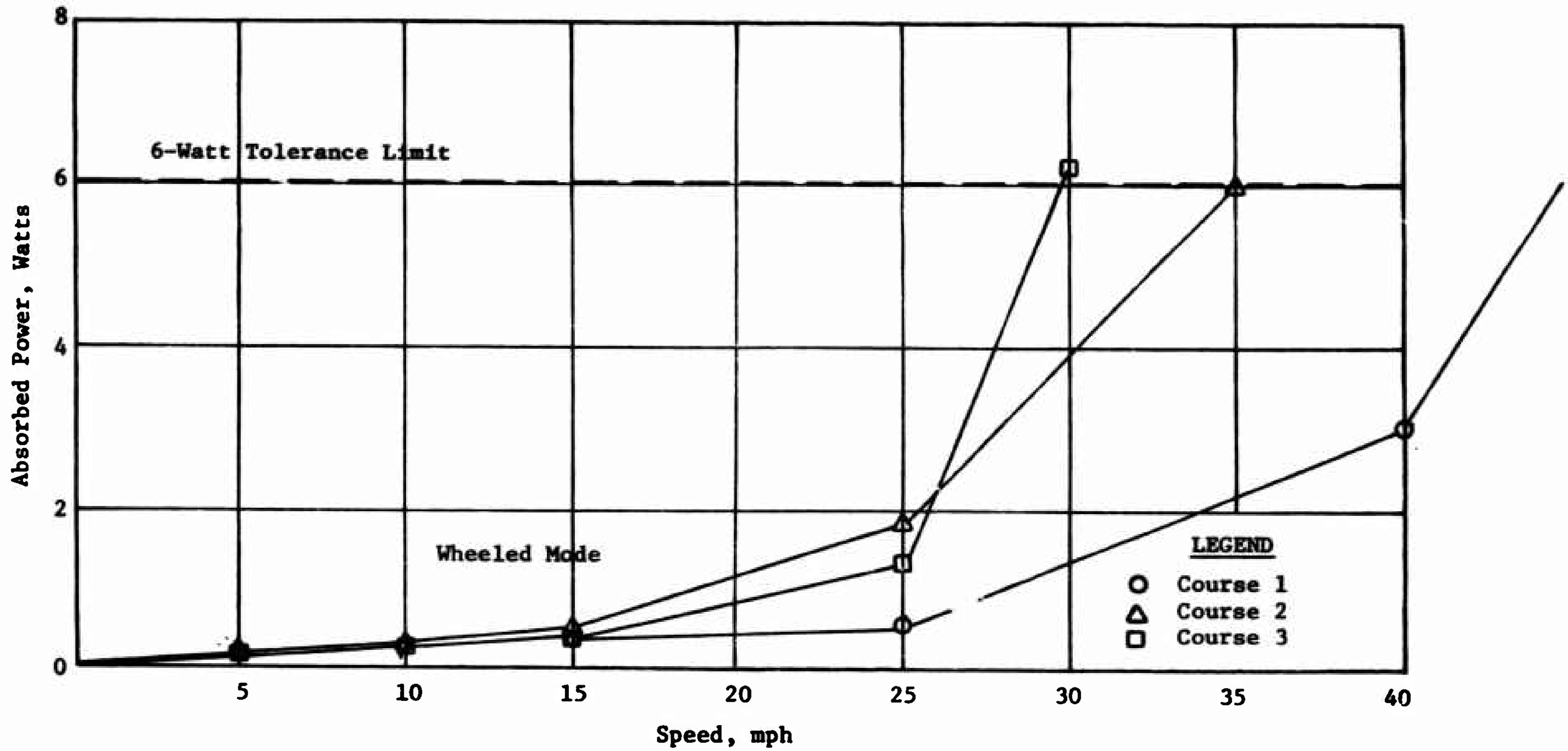
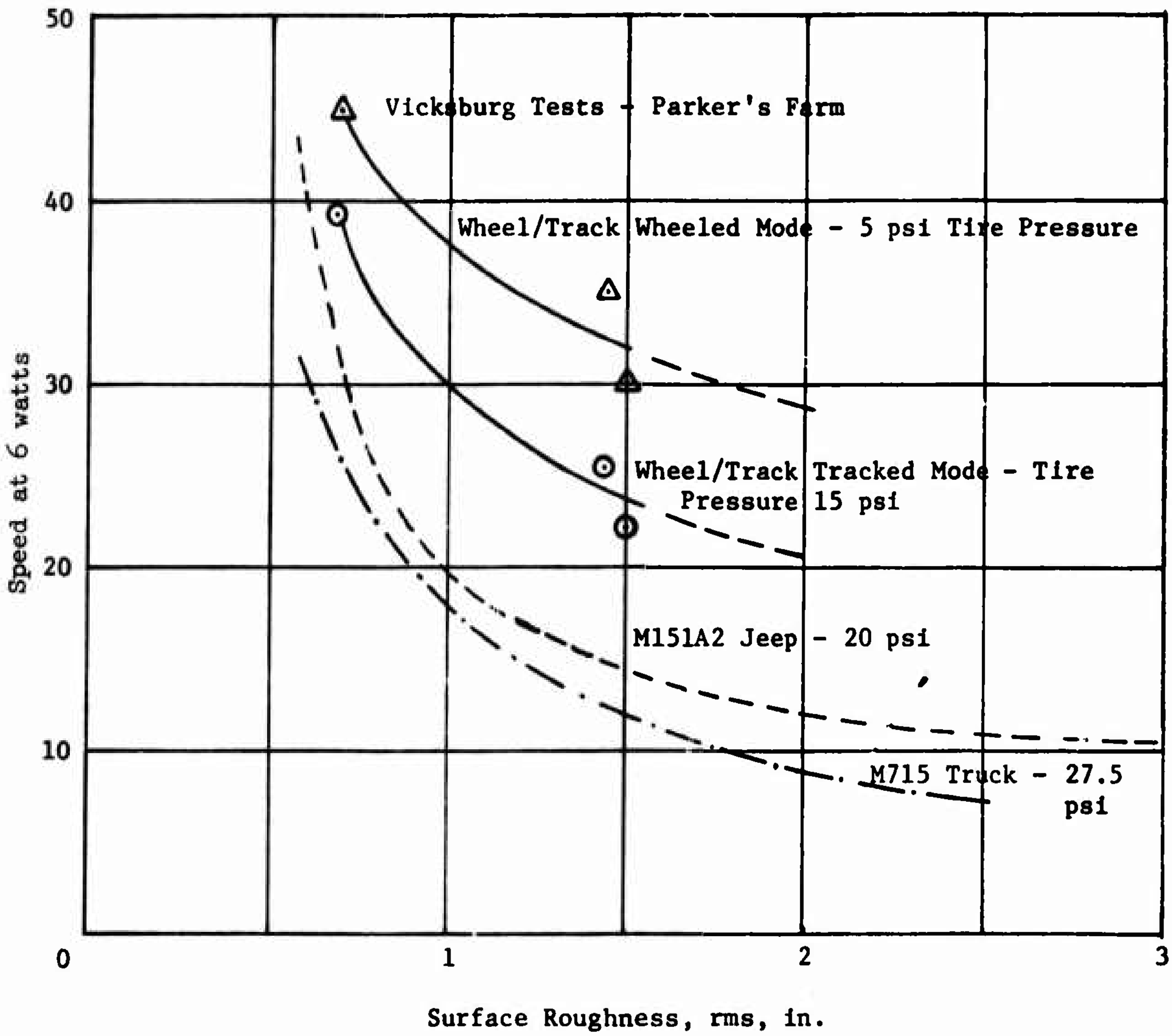


Fig. 15. Absorbed power versus speed, Wheel/Track Convertible, Parker's Farm, Vicksburg, Mississippi, preliminary test results



NOTE: These data represent preliminary tests with the Wheel/Track Convertible. The relation for the M151A2 Jeep represents composite results of four test programs. The relation for the M715 truck was determined from data obtained in another project.

Fig. 16. Comparison of ride quality of selected vehicles

in the 8x4 configuration (second and fourth wheels pulling) for observation of wheel-track interface action at the rear pulling wheels. Three tests in prepared clay (CH) and two in fine sand (SP) were conducted in the wheeled and tracked modes. Soil data for these tests are as follows:

Wheel/Track Test Rig	Test Pit	RCI or CI 0- to 6-in.	Moisture Content, % 0- to 6-in.	Dry Density, lb/ft^3 0- to 6-in.
Wheeled 8x8	Clay (CH)	66	39.50	80.3
Tracked 8x8	Clay (CH)	36	40.00	77.7
Tracked 8x4	Clay (CH)	36	40.00	77.7
Tracked 8x8	Sand (SP)	15	0.05	95.5
Tracked 8x4	Sand (SP)	15	0.05	95.5

39. During drawbar-pull testing the drive axle shafts in the cross-drive unit sheared in the first test. New shafts were not commercially available at test time. Therefore, to complete testing a "shear-pin" system was used to prevent shear of the shafts, which were welded back together. Bolts were installed between the cross-drive and the rear driving wheels, calculated to shear at less than 5000 lb, the approximate shearing strength of the welded shafts. This system allowed completion of the tests, although maximum-drawbar-pull values were not obtained for all test conditions, as shown in table 11.

PART IV: ANALYSIS OF DATA

Tests at Houghton, Michigan

Trail tests

40. Results of trail tests with each vehicle run in clockwise (A-Q) and counterclockwise (Q-A) directions around the closed-loop course are shown in table 2. Speeds obtained in each of the 18 terrain units are included for the various vehicles tested. Analysis of trail unit speeds for A-Q and Q-A directions for each vehicle indicate variations in speeds as affected by the trail factor combinations shown in table 1. For example, Trail Unit A is a relatively open area with a 6.9 percent slope upward in the A-Q direction and downward in the Q-A direction, with minor influences from vegetation and surface roughness. As indicated in table 2, all test vehicles were able to negotiate Trail Unit A in the downslope direction (Q-A) faster than in the upslope direction (A-Q), as expected. Similar results, except as noted below, were obtained for Trail Units B, D, E, H, K, L, N, O, and Q, which had slopes that changed with direction. Conversely, Trail Units C, F, G, I, M, NN, and P were relatively level (slopes less than 1.8 percent) and were considered to have no influence on speeds.

41. Several exceptions to the general trend in speeds occurred for the trail unit groupings listed above. For example, the M151A2, the M29C, and the M104 exhibited equal speeds in Trail Unit B in upslope and downslope directions. This event also occurred in several of the other trail units. Influence from various terrain-driver-vehicle interactions determined most of the speeds in each trail unit, although rapid vehicle acceleration capabilities enabled these lighter vehicles to attain a maximum speed in each trail unit faster than some of the heavier vehicles. Consequently, for those trail units that were relatively smooth and with minimum slope, the M151A2, M29C, and M104 each attained approximately the same speed in upslope and downslope directions.

42. The wheeled version of the Wheel/Track Test Rig generally followed the trend described above for the various trail units, in most cases exhibiting trail unit speeds faster than all vehicles tested, except the M151A2. The lighter M151A2 with a faster acceleration rate achieved faster average speeds in more trail units than did the Test Rig. The ride and handling qualities of the Test Rig were much better, however, than those of the M151A2. The uniquely suspended eight tires on the Test Rig produced smoother, firmer turning characteristics than the four-tire common suspension system used on the M151A2. The soft, low-pressure Terra-tires on the Test Rig combined with the torsilastic suspension through eight independent wheels to smooth abrupt bumps while maintaining a firm trail contact. The M151A2 with four standard military tires at 15-psi pressure bounced over most of the sharp bumps and slid around most of the sharp turns, requiring the driver to decrease speed to maintain vehicle control.

43. The average speed for each trail test was computed by dividing total traverse distance (15,000 ft) by total time to complete the traverse. Results of this computation are shown at the bottom of table 2. The wheeled Test Rig, as indicated, was second only to the M151A2 in overall average speed. In the counterclockwise run, nearly equal or slightly faster speeds were achieved by most vehicles, possibly because only four trail units (B, K, L, and Q) sloped upward in the counterclockwise direction. However, average speeds for each vehicle in the A-Q and Q-A directions were within 1.1 mph of each other.

Traverse tests

44. Results of traverse tests with each vehicle are shown in table 4. Speeds are shown for each vehicle in each terrain unit, along with the gear ranges used for most of the traverse. Included in table 5 is a typical terrain factor description. The low shrubs and low knolls in Terrain Unit 2 slowed all vehicles, except the Test Rig, as much as 1 to 3 mph, as compared with the other two units. The average speed for each vehicle is also included in this summary. Average speeds of

the Test Rig in both wheeled and tracked modes were faster than those of all other vehicles tested. The slowest vehicle of all tested, the M274A2 with no suspension, was affected the most by the surface roughness; consequently, the speeds of the M274A2 were half those of the other vehicles tested. The other unsprung vehicle, the Wolverine, was the next slowest.

45. Descriptions of tests with both modes of the Test Rig, as described by the rider-observer, are included in table 6. The ride and handling characteristics of the Rig were excellent in all three terrain units of Traverse 1. The tracked mode turned much more sharply than the wheeled, probably because of increased traction. The tracked ride, however, deteriorated somewhat from the wheeled ride because of the combined restraining action of the tracks and lock-out bars and increased tire pressure necessary for conversion from wheeled to track mode. The ride in both modes was as good as or better than the ride in all other vehicles.

Special-terrain tests

46. Muskeg tests. Repetitive traffic tests and general maneuvering tests were conducted in muskeg with the wheeled and tracked Test Rig and the Wolverine. Results of repetitive traffic tests are shown in table 7. The Wolverine and wheeled Test Rig completed 22 and 16 passes, respectively, under similar test conditions. The lighter Wolverine (3160 lb versus 5600 lb for the Test Rig) did complete more passes (6), as expected, but with rutting equivalent to that of the Test Rig on the same 0- to 6-in. cone index. The softer underlying layer in the Wolverine test lane perhaps accounted for part of this difference. The Test Rig easily completed 50 passes with only shallow rutting.

47. General maneuvering tests were conducted with the Test Rig and two other vehicles (Wolverine and M29C) to obtain comparative information on relative performance of the Test Rig versus that of the other two vehicles. The Wolverine and the wheeled Test Rig both experienced difficulty in negotiating a sharp turn in the muskeg and were forced to resort to a slow-speed, wide, circular arc to complete

a 360 deg turn; ruts were 4 to 6 in. deep. The M29C and the tracked Test Rig completed sharp, 25- to 30-ft-diam, 360-deg turns with ease and only slight rutting (<2 in.). The tracked Test Rig seemed more aggressive in turning, cutting apart large pieces of the fibrous surface mat and tossing them aside. Both tracked vehicles easily accelerated in open areas and maneuvered easily around scrub vegetation growing in the organic bog. Ride in all vehicles at all speeds was comfortable, and at no time did slippage occur at the wheel-track interface on the Test Rig.

48. Stamped-sand tests. Maximum-speed, drawbar-pull, and towed-motion-resistance tests were conducted with all vehicles in the fine-stamped-sand area at Gay. Results are presented in table 8. Comparing wheeled vehicle performances in table 8 shows that the wheeled Test Rig (289-cu-in. engine) had the highest average speed and the highest maximum sustained drawbar pull, but the second highest towed motion resistance (in terms of percentage of gross vehicle weight). Comparing tracked vehicle performances in table 8 shows that the tracked Test Rig had the highest average speed, the lowest drawbar pulls, and the highest towed motion resistances. Probably the poor performance of the tracked Test Rig when compared with that of the other tracked vehicles can be attributed to track tension and the large area of wheel-track interface.

49. Slope-negotiability tests were conducted in an area of slightly coarser material north of the fine-tailings area. Results of these tests are presented in table 9. As indicated in table 9, all wheeled vehicles except the wheeled Test Rig were unable to negotiate a coarse-grained 33.6 percent slope. The wheeled Test Rig was able to negotiate a 38.8 percent slope at high wheel slip and was immobilized on a 46.0 percent slope. The tracked Test Rig negotiated all slopes before immobilizing on the 54 percent slope, although it experienced difficulty on the 46 percent slope that immobilized the wheeled version. The M104 was unable to negotiate the 46 percent slope and was relatively slow on all other slopes, compared with other tracked vehicles. The

M29C was the best of all vehicles tested in negotiating the slopes, becoming immobilized on a 58 percent slope, although it experienced difficulty on the 54 percent slope.

Tests at Vicksburg, Mississippi

Albemarle Lake wooded, clay site

50. General maneuvering and handling tests were conducted in a very adhesive, alluvial buckshot clay at Vicksburg to analyze wheel-track interaction after extensive mud buildup that occurred during testing. The major concern in these tests was the possibility of slippage at the wheel-track interface with sufficient mud buildup. However, this possibility was ruled out in these tests. Soil buildup measurements indicated an increase in vehicle weight of 1600 lb, or 24 percent of the gross vehicle weight, with no track slip. Vehicle maneuverability was not impaired, although the driver did comment on the sluggishness of the vehicle. He was not aware, however, that the vehicle weighed over 8300 lb because of mud buildup. Photographic coverage of these tests supported the fact that no slip was experienced in the wheel-track system. The wheeled version of the Test Rig also performed rather well, although, not unexpectedly, it was somewhat hampered by traction difficulties. The wheeled version operated in the same soft-soil areas as the tracked version and suffered only one immobilization. This occurred near the water's edge in very soft soil, RCI = 11. However, the wheeled vehicle almost completed the one pass on RCI of 11 necessary to establish the experimental VCI_1 of the wheeled version at approximately the computed VCI_1 of 11 (table 12). The tracked version was not immobilized during these tests, although large quantities of mud accumulated in the vehicle running gear on RCI = 11. The computed $VCI_1 = 9$ for the tracked version (table 12) was not verified by tests because of unavailability of a test area with RCI $<$ 11.

51. Three dynamics courses were selected at Parker's Farm to determine vehicle dynamic response at various speeds over three levels

of surface roughness, 0.67, 1.44, and 1.49 in. (rms elevations), respectively. Time restrictions and nonavailability of courses precluded testing over a range of surface roughnesses, as is customary for development of a complete surface roughness-speed curve. Therefore, the results shown in fig. 16 reflect only preliminary test results. However, fig. 16 does indicate the outstanding ride performance of the Test Rig, in both modes, compared with that of two of the test vehicles used in this program. During traverse and trail tests at Houghton, both driver and rider-observer remarked on the smooth ride of the Test Rig. However, the vehicles were not tested over strictly ride dynamics courses for comparative purposes, and other vehicle factors overshadowed to some extent this particular vehicle attribute. Future testing, as scheduled in table A9 of the Plan of Tests (Appendix A), should provide sufficient information to analyze vehicle dynamic response more thoroughly and to finalize comparisons of ride qualities of the Test Rig with those of other vehicles.

Grassy slopes

52. Five grassy slopes, two clay at Albemarle and three silt at WES, were used for slope testing with the wheeled vehicles. As explained in paragraph 34, no speed tests were attempted with the tracked Test Rig. However, with sufficiently strong drive shafts the tracked version should outperform the wheeled on firm grass slopes because of the added traction. Results of these slope tests are shown in table 10. Side-slope tests conducted on the two clay slopes and the least silt slope produced no apparent detrimental effects on the vehicle. (The steepest silt side slopes were not used for safety reasons.) The vehicle performed well on the side slopes, with no wheel-track interface slip or side-slope slippage observed, either visually or through photographic coverage.

WES facility clay and sand pits

53. Five drawbar-pull and five towed-motion-resistance tests were conducted in the WES laboratory with the Test Rig in dry sand (SP) and buckshot clay (CH) as presented in fig. 17. A test with the wheeled

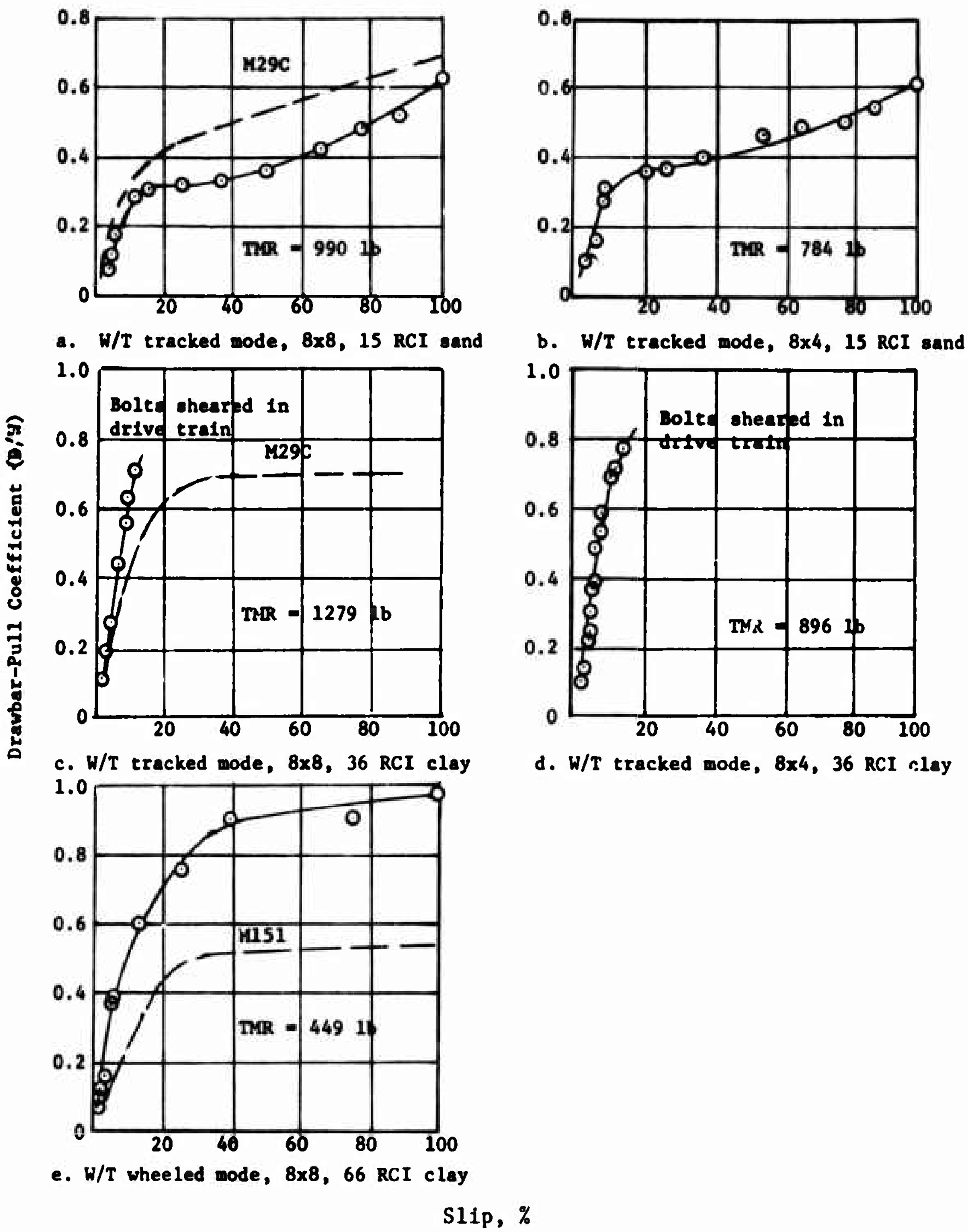


Fig. 17. Drawbar-pull coefficient versus slip, W/T convertible and comparison vehicles, laboratory prepared sand and clay

version only was conducted on a 66-RCI clay. During this test the drive shafts sheared as discussed in paragraph 39. At the time of shear, the vehicle was developing 5394 lb of drawbar pull, or a drawbar-pull coefficient (D/W) of 0.96, on relatively firm clay, an extremely high coefficient for any wheeled vehicle. For comparison, an average curve for the M151 on 66 RCI is shown in fig. 17e. Note that the maximum D/W for the M151 is near 0.54, substantially less than 0.96. Tests on clay and sand with the tracked version of the Test Rig were conducted in 8x8 and 8x4 configurations to determine the effects of drawbar pull on the rear powered road arm in each set. No significant effects could be determined from these tests, although the 8x4 seemed to develop more pull at lower slip values in sand. Also drawbar pulls in both configurations are slightly less than those pulls of the M29C weasel at equal slip values. The 8x8 and 8x4 tracked Test Rigs were unable to complete the drawbar-pull tests on the 36-RCI clay. The "shear-pin" system failed in both tests at drawbar-pull values less than maximum. Therefore, no firm conclusions can be reached from the 36-RCI tests, although the curves indicate pulls in excess of those of the M29C comparison vehicle.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

54. The results of the test program with the Interim Wheel/Track Convertible Test Rig may be summarized as follows:

- a. The Test Rig performed well in a variety of terrain conditions, generally equaling or exceeding the performance of both the wheeled and tracked comparison vehicles in the respective modes. Vehicle ride and handling characteristics are two of the most promising features of the vehicle, permitting relatively rapid speeds over rugged terrain at comfortable ride levels.
- b. The powered, suspended road arm system on the Test Rig was found to be practical, especially in the wheeled mode. Some mechanical problems occurred in initial tests with the tracked mode, but were not unique for a first-generation vehicle.
- c. In trail tests the power train of the Test Rig appeared inadequate in rapidly accelerating between turns and obstacles and in maneuvering. The vehicle outperformed all vehicles except the M151A2. The Test Rig ride was much firmer, yet more comfortable than that of the M151A2, although insufficient acceleration of the Test Rig prevented the vehicle from exceeding the speeds attainable by the M151A2 (paragraphs 42 and 43).
- d. During all phases of testing, the track wrap-around concept proved effective in increasing drawbar pull, slope negotiability, maneuverability, and soft-soil performance compared with those of the wheeled version. At no time did the track slip off the tires, nor did slip occur at the wheel-track interface (paragraphs 45-50, 53).

e. The Wheel/Track Convertible Test Rig concept appears practicable, and limited performance tests herein suggest a full-scale test program after final modifications of the Rig (paragraphs 42-50, 52, 53).

Recommendations

55. It is recommended that:

a. Any excessive weight be removed from the Test Rig to permit faster accelerations, or a more efficient and powerful power train be installed for future tests.

b. Future test programs, as outlined in the plan of tests, (Appendix A) be implemented, following any redesign modifications deemed necessary as a result of these tests.

Table 1

Summary of Terrain Data, TACOM Trail Course 2 (Clockwise)

Measured Values

Trail Unit No.	Trail Unit Distance, ft	Terrain Factor Value																			
		Surface Type	Surface Strength, RCI	Slope, %	Obstacle Angle, deg	Obst Vert Mag, in.	Obst Base Width, in.	Obstacle Length, ft	Obstacle Spacing, ft	Obstacle Spacing Type	Surface Roughness, in.	Obstacle Spacing of Stems								Recognition Distance, ft
												> Class 1, ft	> Class 2, ft	> Class 3, ft	> Class 4, ft	> Class 5, ft	> Class 6, ft	> Class 7, ft	> Class 8, ft	
A	228	2	623	6.9	179	0.1	142	0.66	197	2	2.08	328	328	328	328	328	328	328	328	150
B	234	2	623	13.2	179	0.1	142	0.66	197	2	1.34	12	12	12	12	12	12	12	12	164
C	1378	2	391	1.8	179	0.1	142	0.66	197	2	1.25	328	328	328	328	328	328	328	328	150
D	680	2	750	4.7	179	0.1	142	0.66	197	2	0.47	15	15	15	15	15	15	15	15	75
E	280	2	750	9.3	179	0.1	142	0.66	197	2	1.55	12	12	12	12	12	12	12	12	150
F	1815	2	366	0.4	179	0.1	142	0.66	197	2	1.18	328	328	328	328	328	328	328	328	164
G	2273	2	750	1.8	179	0.1	142	0.66	197	2	0.29	12	12	12	12	12	12	12	12	150
H	257	2	218	10.9	179	0.1	142	0.66	197	2	1.59	328	328	328	328	328	328	328	328	100
I	535	2	216	0.9	179	0.1	142	0.66	197	2	2.01	12	12	12	12	12	12	12	12	90
J	1820	2	750	0.4	179	0.1	142	0.66	197	2	0.47	328	328	328	328	328	328	328	328	164
K	375	2	512	8.3	179	0.1	142	0.66	197	2	0.62	15	15	15	15	15	15	15	15	150
L	1325	2	380	3.6	179	0.1	142	0.66	197	2	2.50	11	11	11	11	11	11	11	11	40
M	1300	2	750	1.0	179	0.1	142	0.66	197	2	1.17	328	328	328	328	328	328	328	328	150
N	42	2*	447	3.5	192	48	144	492	42	2	6.17	328	328	328	328	328	328	328	328	164
NN	1958	2	750	1.1	179	0.1	142	0.66	197	2	1.15	328	328	328	328	328	328	328	328	142
O	220	2	301	32.3	179	0.1	142	0.66	197	2	3.18	20	20	20	20	20	20	20	20	164
P	30	2	750	0	202	96	132	492	30	2	9.91	328	328	328	328	328	328	328	328	35
Q	250	2	623	10.6	179	0.1	142	0.66	197	2	1.90	328	328	328	328	328	328	328	328	150

* Stream crossing.

(Continued)

Table 1 (Concluded)

Factor Classes

Trail Unit No.	Trail Unit Distance, ft	Terrain Factor Value																		
		Surface Type	Surface Strength, RCI	Slope, %	Obstacle Angle, deg	Obst Vert Mag, in.	Obst Base Width, in.	Obstacle Length, ft	Obstacle Spacing, ft	Obstacle Spacing Type	Surface Roughness, in.	Obstacle Spacing of Stems								Recognition Distance, ft
												> Class 1, ft	> Class 2, ft	> Class 3, ft	> Class 4, ft	> Class 5, ft	> Class 6, ft	> Class 7, ft	> Class 8, ft	
A	228	2	1	3	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	2
B	234	2	1	4	1	1	1	1	1	2	2	7	7	7	7	7	7	7	7	2
C	1378	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
D	680	2	1	2	1	1	1	1	1	2	2	6	6	6	6	6	6	6	6	3
E	280	2	1	3	1	1	1	1	1	2	3	7	7	7	7	7	7	7	7	2
F	1815	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
G	2273	2	1	1	1	1	1	1	1	2	1	7	7	7	7	7	7	7	7	2
H	257	2	3	4	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	2
I	535	2	3	1	1	1	1	1	1	2	3	7	7	7	7	7	7	7	7	2
J	1820	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
K	375	2	1	3	1	1	1	1	1	2	2	6	6	6	6	6	6	6	6	2
L	1325	2	1	2	1	1	1	1	1	2	3	7	7	7	7	7	7	7	7	3
M	1300	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
N	42	2	1	2	8	7	1	7	3	2	7	1	1	1	1	1	1	1	1	2
NN	1958	2	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
O	220	2	1	5	1	1	1	1	1	2	4	5	5	5	5	5	5	5	5	2
P	30	2	1	1	8	7	1	7	4	2	9	1	1	1	1	1	1	1	1	4
Q	250	2	1	4	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	2

Table 2. TACOM Trail Course 2, Average Speeds, mph

Trail Unit	Distance ft	Slope with Respect to Travel Direction* A-Q	Q-A	Wheel/Track (wheeled mode) A-Q	Q-A	M151A2 A-Q	Q-A	Wolverine A-Q	Q-A	M274A2 A-Q	Q-A	M715 A-Q	Q-A	M29C A-Q	Q-A	M104 A-Q	Q-A
A	228	Up	Down	15.5	17.3	18.1	18.5	12.6	14.1	8.6	11.1	12.7	16.5	10.5	13.0	11.1	12.1
B	234	Down	Up	17.3	16.0	19.0	19.0	12.5	10.7	12.3	7.6	14.0	12.3	11.8	11.8	11.5	11.6
C	1378	-**	-	22.5	22.1	23.9	26.1	16.7	17.2	12.6	15.4	20.5	24.6	15.7	18.4	15.1	14.5
D	680	Up	Down	18,0	19.8	20.2	22.1	14.7	15.4	11.5	14.7	18.0	20.2	13.4	16.1	14.3	13.7
E	280	Up	Down	17.4	20.8	17.4	21.7	13.0	14.7	5.8	14.7	17.4	18.7	13.0	14.5	12.9	13.2
F	1815	-	-	20.3	21.1	23.3	23.1	14.6	14.1	11.3	11.3	19.1	19.6	14.1	15.0	15.8	12.8
G	2273	-	-	25.8	24.6	29.8	30.4	18.4	19.0	13.9	13.9	25.0	26.3	19.3	18.6	18.3	14.5
H	257	Up	Down	11.0	13.3	12.7	14.4	8.1	9.4	5.5	8.6	7.2	10.1	4.8	8.2	7.9	9.1
I	535	-	-	11.3	11.9	13.5	12.9	8.6	9.1	7.3	7.2	8.5	8.8	8.0	8.1	9.1	8.8
J	1820	-	-	24.4	25.9	28.7	30.3	19.0	19.5	15.9	14.8	27.6	26.0	17.1	17.0	16.6	14.2
K	375	Down	Up	21.7	21.7	25.6	22.8	15.8	14.7	16.8	7.3	22.8	19.4	14.8	12.7	15.8	11.7
L	1325	Down	Up	11.5	13.0	13.7	14.3	10.1	10.2	9.9	7.3	8.8	9.9	7.7	8.0	8.9	9.2
M	1300	-	-	16.1	18.8	20.5	21.3	15.0	13.3	11.4	10.2	17.6	17.2	12.1	13.8	11.5	12.0
N †	42	Up	Down	5.5	6.2	9.0	6.8	5.3	6.4	3.4	4.1	6.8	9.5	5.1	7.0	4.9	5.7
NN	1958	-	-	18.8	19.1	23.3	24.7	16.3	15.0	11.5	13.1	19.7	19.2	13.7	15.3	13.0	13.1
O	220	Up	Down	8.8	11.7	10.6	11.1	7.1	7.6	4.0	5.7	9.3	8.2	5.8	8.5	5.1	6.1
P ††	30	-	-	5.1	6.4	4.9	6.4	5.1	5.1	4.1	3.4	6.0	4.7	3.9	4.8	3.9	4.4
Q	250	Down	Up	12.2	11.2	15.0	12.9	10.0	8.8	8.9	5.6	11.2	10.7	8.5	8.0	8.5	7.5
Trail	15,000			17.8	18.9	20.9	21.6	14.2	14.1	11.0	11.0	16.6	17.4	12.5	13.6	12.9	12.1

* Vehicles were run clockwise (A-Q) and counterclockwise (Q-A) around closed loop of Trail Course to determine effects of vehicle passage in both directions in trail units.

** Dashes indicate negligible slope.

† Stream crossing.

†† Road crossing.

Table 3

Test Notes
TACOM Trail Course 2
Wheel/Track Convertible Test Rig (Wheeled Mode)
(Clockwise)

Trail Unit No.	Trail Unit Length, ft	Time in Trail Unit, sec	Avg Speed in trail Unit, mph	Trail Factors Exerting Most Influence on Speed	Notes and Observations of Rider/Observer During Test
A	228	10.0	15.5	6.9% upslope	Speed at start of trail unit 15 mph up slope; speed up to 20 mph near road crossing at "B"; driver slowed slightly before going downslope at "B"
B	234	9.2	17.3	12' wide trail, 13.2% downslope. Some surface roughness	Speed downslope 17 mph; some slight roughness but ride very good, suspension very effective in minimizing abrupt bumps
C	1378	41.8	22.5	Some surface roughness	Speed at start of unit 20 mph; some vehicle side-skid on loose material, but handling and stability of vehicle excellent. Acceleration in loose material with surface roughness fair. Speed increased to 28 mph near end of terrain unit. Crossed bridge over creek at approximately 15 mph.
D	680	25.8	18.0	15' wide trail, visibility only 75', some roughness	Again vehicle "slid" around turn at "D", but handling and stability very good. Speed down to 9 mph after skid, but driver accelerated to 24 mph before maintaining constant 20 mph for remainder of terrain unit; slowed to 15 mph for left turn at E
E	280	11.0	17.4	12' wide trail; some surface roughness; 9.3% upslope	Vehicle accelerated at 16 mph from E, reaching 20 mph near crest of slope at F
F	1815	61.0	20.3	Surface roughness	Some side skid on green grass at F. Driver accelerated in open field to 25 mph before surface roughness held speed to 22-25. Suspension very effective in maintaining smooth ride over rough surface irregularities. Driver had to slow to 11 mph to complete 360° loop at end of field.
G	2273	60.2	25.8	12' wide trail	Speed at "G" of 17 mph. Accelerated along virtual "tunnel" in vegetation over smooth trail to 30 mph. Held this speed for majority of trail unit, slowing at "H" to 7 mph to go upslope
H	257	16.0	11.0	10.9% upslope; visibility cut to 100' by vegetation	Speed up slope of 7 mph. Speed in maneuver area before "I" about 12-15 mph.
I	535	32.2	11.3	12' wide trail; visibility in vegetation cut to 90', surface very irregular and rough	Speed entering unit 13 mph. Some "bottoming" on jounce stops over roughest bumps, but suspension remains very effective in minimizing harsh jolts over edges of irregularities. Driver alternately pushed gas pedal between surface features and released pedal at features to reduce impact on jounce stops. Some slight maneuvering in addition to surface roughness held speed to 11 mph most of unit.
J	1820	50.8	24.4	None	This trail unit is actually a sandy tertiary road. Vehicle acceleration probably influenced average speed in the unit the most. Entered unit at 12 mph. Rapidly accelerated to 30 mph and maintained about this speed for most of the unit. Slowed to 25 mph as approached "K".
K	375	11.8	21.7	15' wide trail; 8.3% downslope. Some roughness problem	Entered trail unit at 25 mph but driver gradually slowed vehicle because of downslope and anticipated sharp left turn at "L"
L	1325	78.8	11.5	11' wide trail; 3.6% downslope. Maneuver caused by close proximity of large trees to edge of trail; visibility cut to 40'	Speed governed by maneuver in woods along a narrow trail; entered unit at 11 mph, but speed cut to about 8-10 mph by maneuver, visibility and roughness. Speeds up to 10-12 mph between turns and maneuvers.
M	1300	55.0	16.1	Surface roughness; maneuver	Entered stamped rock area at about 12 mph. Accelerated to 22 mph rapidly but slowed somewhat by maneuver around small trees. Slowed to about 14 mph upon approach to creek crossing at "N"
N	42	5.2	5.5	Surface roughness and obstacles (stream banks)	Entered creek at 13 mph. Water depth 12" with rocky stream bottom. Steep stream bank at "NN". Some wheel slip on bank caused by wave action during crossing.
NN	1958	71.0	18.8	Surface roughness	Entered stamped rock area again at 4-6 mph. Accelerated rapidly to constant 14 mph for maneuver in small stand of pines. Exited pine area and accelerated on stamped rock to 24 mph. Speed slowed at times to 20 mph by surface irregularities.
O	220	17.0	8.8	Surface roughness; 32.3% upslope	Upslope on steep sandy surface at 8 mph. Speed down to 5-6 mph at crest of slope. Driver accelerated slightly on flat area between crest of slope and top of bank at edge of road
P	30	4.0	5.1	U-shaped road crossing presented surface roughness and obstacle problems; visibility only 30 ft	Driver slowed at bank edge and eased down onto road bed about 6 mph. Speed down to 4-5 mph at top of opposite bank.
Q	250	14.0	12.2	Surface roughness; 10.6% downslope	Driver accelerated downslope toward end of test. Some surface irregularities slowed speed down to 12-15 mph near end of test.

(Continued)

Table 3 (Concluded)

Trail Unit No.	Trail Unit Length, ft	Time in Trail Unit, sec	Avg Speed in Trail Unit, mph	Trail Factors Exerting Most Influence on Speed	Notes and Observations of Rider/Observer During Test
Q	250	15.2	11.2	Surface roughness; 10.6% upslope	Speed at start of trail unit 15 mph; upslope at 10 mph after turn towards Q; some surface roughness
P	30	3.2	6.4	U-shaped road crossing presented surface roughness & obstacle problems; visibility only 30 ft	Driver slowed at bank edge to about 6 mph. Eased down onto road and then back up other bank at 4-5 mph.
O	220	12.8	11.7	Surface roughness; 32.3% downslope.	Driver eased over crest at 8 mph; held brake until about half-way down slope, then driver allowed vehicle to roll down remainder of slope, gaining speed as vehicle passed "O" about 15 mph
NN	1958	70.0	19.1	Surface roughness	When vehicle entered stamped rock area driver began accelerating; vehicle speed up to 24-26 mph which driver held for majority of trail unit; slowed to 15 mph in pine area before creek to maneuver
N	42	4.6	6.2	Surface roughness; obstacles (stream banks)	Driver slowed vehicle to 4-6 mph before entering water; exited water at 6 mph
M	1300	47.2	18.8	Surface roughness; maneuver	Accelerated away from creek up to 15-16 mph; maneuver in pines out onto stamped rock at 21 mph; speed 19-20 mph in turns and 24-25 mph on straight portions of trail; 26-27 mph before slowing to enter woods at 18 mph
L	1325	69.4	13.0	11' wide trail; 3.6% upslope; maneuver caused by close proximity of large trees to trail edge. Visibility only 40'.	Speed cut to 8 mph by maneuver and narrow trail; up to 10-11 mph on straight portions of trail; some surface roughness. Accelerated to 18 mph before entering area requiring most maneuver. Speed 11 to 13 mph in this area.
K	375	11.8	21.7	15' wide trail; 8.3% upslope; some surface roughness	After turning onto trail from woods at 13 mph, driver accelerated upslope to 22 mph for remainder of trail unit.
J	1820	48.0	25.9	None	Acceleration influenced speed most. Driver entered terrain unit at much faster speed than he did on clockwise test A-Q. Speed 30 mph most of trail unit.
I	535	30.6	11.9	12' wide trail; visibility 90' surface very irregular and rough	Surface roughness held speed to 10-12 mph for entire unit. Driver accelerated between irregularities but eased off on gas over irregularities to lessen abruptness of bumps. Ride still rather comfortable.
H	257	13.2	13.3	10.9% downslope; visibility of 100'	Entered trail unit at 10-12 mph but speed increased downslope to 15 mph before turn into terrain unit "G"
G	2273	63.0	24.6	12' wide trail	Accelerated up to 30 mph and held this speed for most of unit. Speed down to 26 for turns.
F	1815	58.6	21.1	Surface roughness	Slowed to 18 mph for turn at "G". Surface roughness and turning held speed to 14 mph for loop turn-around. Accelerated to 30 in open field before surface roughness cut speed to 20 mph. Ride good over roughest areas.
E	280	9.2	20.8	12' wide trail; some surface roughness, 9.3% downslope	Entered unit at 25 mph but slowed to 22 mph going downhill. Speed down to 15 mph for turn into "D".
D	680	23.4	19.8	15' wide trail; visibility only 75'; some surface roughness	Accelerated on rocky surface from 15 mph to 22 before vehicle began sliding around turns. Driver slowed to 12-15 mph for turn at bridge.
C	1378	42.6	22.1	Some surface roughness	Crossed bridge at 15 mph and onto stamped rock area where driver accelerated to 30 mph. Skid on turns cut speed to 24-26 mph. Speed down to 18 mph for turn up slope into "B".
B	234	10.0	16.0	12' wide trail; 13.2% upslope; some surface roughness	Entered trail unit at 18 mph; speed slowed to 15-16 mph upslope by slope & roughness.
A	228	9.0	17.3	6.9% downslope	Driver passed crest of slope at 16 mph and accelerated toward end of test. Slight turn near end of test slowed speed down slightly from 20 mph.

Table 4

Traverse Speed Tests
Traverse 1, Ahmeek, Michigan

Vehicle	Gear or Range	Speed, mph Terrain Unit 1	Terrain Unit 2	Terrain Unit 3	Average Speed
Wheeled					
Wheel/Track Test Rig	High-Drive	19.3	17.1	16.7	17.4
M151A2	2nd or 3rd	17.9	15.1	18.2	17.1
Wolverine	2nd	14.9	11.3	12.5	12.5
M274A2	High-1st	8.6	7.0	7.4	7.5
M715	2nd or 3rd	14.0	12.5	13.8	13.4
Tracked					
Wheel/Track Test Rig	High-Drive	18.4	17.3	17.1	17.5
M29C	High-1st & 2nd	14.9	11.9	15.3	14.0
M104	Low-Drive	14.0	12.5	13.8	13.4

Table 5

Summary of Terrain Data
Traverse 1

Terrain Unit No.	Terrain Unit Distance, ft	Terrain Factor Value: Surface Type	Surface Strength, RCI	Slope, %	Obstacle Angle, deg	Obst Vert Mag, in.	Obst Base Width, in.	Obstacle Length, ft	Obstacle Spacing, ft	Obstacle Spacing Type	Surface Roughness	Obstacle Spacing of Stems > Class 1, ft	Obstacle Spacing of Stems > Class 2, ft	Obstacle Spacing of Stems > Class 3, ft	Obstacle Spacing of Stems > Class 4, ft	Obstacle Spacing of Stems > Class 5, ft	Obstacle Spacing of Stems > Class 6, ft	Obstacle Spacing of Stems > Class 7, ft	Obstacle Spacing of Stems > Class 8, ft	Recognition Distance, ft
1	550	2	255	1.7	179	0.1	142	0.66	197	2	1.87	328	328	328	328	328	328	328	328	58
2	750	2	288	2.6	179	0.1	142	0.66	197	2	1.60	11.2	14.4	24.1	32.7	328	328	328	328	38
3	1046	2	231	0.6	179	0.1	142	0.66	197	2	2.14	328	328	328	328	328	328	328	328	49

Table 6

Test Notes, Traverse 1, Ahmeek, Michigan, Wheeled/Tracked Convertible Test Rig.

Terrain Unit No.	Terrain Unit Length, ft	Time in Terrain Unit sec	Avg Speed in Terrain Unit mph	Terrain Factors Exerting Most Influence on Speed	Notes and Observations of Rider-Observer During Test
				Wheeled Mode	
1	550	19.4	19.3	Surface roughness; visibility	Speed at start of test - 22 mph; ride and stability good; speed up to 24 mph near mid-point of terrain unit; surface roughness increased as vehicle approached end of terrain unit; speed 18 mph
2	750	30.0	17.1	Surface roughness; maneuver; visibility	Jounce stops hit hard in rocky area near small trees, speed 16-17 mph; driver maneuvered around trees and over small rocky knolls at 16-20 mph; handling of vehicle excellect, ride comfortable
3	1046	42.6	16.7	Surface roughness; visibility	Speed at start of unit 20 mph; roughness slowed speed to 16-17 mph for remainder of test; ride sometimes degraded by severity of bumps, but overall, still good
				Tracked Mode	
1	550	20.4	18.4	Surface roughness; visibility	Speed at start of test 26 mph; ride as good as that of wheeled mode; speed up to 30 mph in middle of terrain unit, down to 16-20 mph near Terrain Unit 2
2	750	29.6	17.3	Surface roughness; maneuver; visibility	Entered Unit 2 at 25 mph; vehicle maneuvers around trees sharper than wheeled mode, probably from increased traction; speed over rocky knolls 16-20 mph
3	1046	41.6	17.1	Surface roughness; visibility	Speed at start of unit - 27 mph, but speed gradually slowed by surface roughness to 16-20 mph; bumps are somewhat harsher on ride in tracked mode, probably because of loss of cushioning effect of low pressure tires in wheeled mode; somewhat less mobility of suspension because of union of tire pairs with tracks

Table 7

Confined Muskeg Trafficability Tests

Vehicle	Pass No.	Cone Index sfc	1	2	3	4	5	6	9	12	15	18	24	30	36	Avg Cone Index 0-6	Avg Cone Index 6-12	Rut Depth in.	Remarks
Wheel/Track Test Rig (Tracked mode, 289-cu-in. engine)	0	16	21	24	28	32	28	29	26	32	29	32	30	37	39	25	29	-	
	1																	1	Vehicle pressed down grasses & mosses: very little rutting
	5																	2-1/2	Some slight surface water: dark organic material beginning to appear
	10																	3-1/2	Ruts filled with thin layer of dark organic muck
	20																	4-1/2	Vehicle had matted layer of roots & fibers preventing it from cutting through; some surface water
	30																	5	Significant rutting nearly complete by this pass
	40																	5-1/4	Very little change in ruts
	50	8	37	67	30	27	24	24	25	29	29	29	31	29	30			5-1/2	Vehicle had compacted mat system to very hard 2 in. layer of fibers that prevented significant rutting. Completed 50 passes with ease.
Wheel/Track Test Rig (Wheeled mode, 289-cu-in. engine)	0	14	16	16	22	31	29	34	30	31	40	35	31	38	43	25	34	-	
	1																	4-1/2	Vehicle pressed moss and root mat down and ruts began filling with water
	5																	11-1/2	Vehicle had cut through mat by 5th pass
	10																	13	Hull dragging and wheels bulldozing large volume of loose organic material
	15																	15	Vehicle hull dragging throughout lane
	16	25	30	35	25	24	32	30	32	34	32	28	30	36	33			16	Vehicle immobilized at end of lane after completing 16th pass with difficulty. Vehicle was able to extricate itself.
Wolverine	0	15	19	27	32	29	25	26	27	24	23	30	30	27	28	25	26	-	
	1																	2-1/2	Some chewing of mat by wheels
	5																	7	Wheels cut through mat on 5th pass
	10																	10-1/2	Hull flange next to wheels dragging on 10th pass
	15																	13-1/2	Vehicle pushing large quantity of loose material behind wheels
	20																	15	Hull beginning to drag
	22	21	24	22	23	25	30	24	27	24	25	25	24	23	22			15-1/2	Vehicle immobilized on 23rd pass near start of test - hull dragging along entire test lane. Vehicle was able to extricate itself by backing up.

Table 8

Results of Speed, Drawbar-Pull, and Towed-Motion-Resistance Tests
Stamped Sand, Gay, Michigan

Vehicle	Gear or Range	Avg speed, mph	Maximum Sustained Drawbar Pull lb	Maximum Sustained Drawbar Pull Percent of Gross Wt	Avg Towed Motion Resistance lb	Avg Towed Motion Resistance Percent of Gross Wt
			Wheeled			
Wheel/Track Test Rig, (141-cu-in. engine)	High-Drive Low-Drive	18.8 19.7	1900	33.9	440	7.8
(289-cu-in. engine)	High-Drive	36.9	1900	33.9	440	7.8
M151A2	3rd	29.7**	560	17.5	220	6.9
Wolverine	3rd	27.1	900	28.8	460	14.5
M274A2	High-2nd Low-3rd	14.2 11.5	520	24.8	120	5.7
			Tracked			
Wheel/Track Test Rig, (141-cu-in. engine)	Inoperable - mechanical difficulties					
(289-cu-in. engine)	High-Drive	24.6	2300	34.3	800	11.9
M29C	High-2nd	23.0	3000	52.6	400	7.0
M104	High-Drive	20.5	2400	41.7	430	7.5

* In the motion-resistance tests, the vehicle transmission was in neutral.

** The M151A2 used in this test was experiencing carburetor problems. The vehicle was repaired after these tests, but another speed test was not conducted. The speed shown does not reflect the maximum performance of a standard M151A2.

Ta

Slope Tests a

Vehicle	Slope 1 15.3% Gear	Slope 1 Speed, mph	Slope 1 Remarks	Slope 2 23.8% Gear	Slope 2 Speed, mph	Slope 2 Remarks	Slope 3 27.6% Gear	Slope 3 Speed, mph	Slope 3 Remarks	Slope 4 33.6% Gear	Slope 4 Speed, mph	
Wheel/Track Test Rig (Wheeled mode, 289-cu-in. engine)	Drive	12.3		Drive	7.9	Driver had difficulty in "low" gear because of wheel spin; therefore used "drive" which was rather slow.	Low	10.0	Vehicle negotiated slope with ease.	Low	7.7	Some near slop
M151A2			*			*	2nd	10.0**	Vehicle had troble on several runs getting started in loose "sand".		No Go	Vehi slip toe immo way
Wolverine			*	1st	7.2	Some spin at toe & crest of slope	1st	7.3	Some spin at toe & crest of slope		No Go	Vehi boun down slip mobi
M274A2			*			*	Low-1	3.0**	Vehicle had difficulty on most slopes because of traction loss on loose sand and light weight		No Go	Vehi oped abo upsl
Wheel/Track Test Rig (tracked mode, 289-cu-in. engine)			*			*	Low	8.1		Low	6.6	Vehi tia with
M29C			*			*			*	Low-2	6.3	
M104			*			*			*	Low-Low	5.1	Vehi up

* Speeds were measured only for those slopes near the maximum negotiable for the vehicles determined from preliminary testing.

** These speeds are averages of several runs, not a best speed as are the others on this page. During preliminary tests with these two vehicles seve depending on wheel slip or surface irregularities, so these runs were averaged to obtain the speed shown in this table.

Slope Tests at

Vehicle	Grassy Clay Slope 1, 25% Range/Gear	Speed, mph	Remarks	Slope 2, 35% Range/Gear	Speed, mph	Remarks
Wheel/Track Test Rig (Wheeled, 289-cu-in. engine)	Low-2nd	9.7	Slight slip at toe	Low-2nd	9.0	Vehicle showing slightly near crest
M151	1st-2nd	9.3	Some wheel slip at toe of slope	1st-2nd	8.8	Vehicle slowing slightly near crest
Wolverine	1st	8.8	Some wheel slip at toe	1st-2nd	8.5	Vehicle slowing slightly near crest

* The Wolverine was inoperable because of mechanical difficulties and was not repaired in tim

Table 9

Slope Tests at Houghton, Michigan

	Slope 4 33.6%			Slope 5 38.8%			Slope 6 46.0%			Slope 7 54.0%		
rks	Gear	Speed, mph	Remarks	Gear	Speed, mph	Remarks	Gear	Speed, mph	Remarks	Gear	Speed, mph	Remark
egotiated ch ease.	Low	7.7	Some wheel spin near crest of slope.	High	5.9	Near 100% slip at crest but vehicle had sufficient power to complete test with wheels spinning.		No Go	Vehicle immobilized at toe of slope.			
had tro- everal ting in loose		No Go	Vehicle began slipping near toe of slope & immoblized 2/3 way up slope.									
n at toe of slope		No Go	Vehicle began bouncing up & down near 100% slip before immobilization.									
had dif- on most ecause of loss on nd and ight		No Go	Vehicle developed 100% slip about 2/3 way upslope.									
	Low	6.6	Vehicle negotiated slope with ease.	Low	5.4	Some slip about 2/3 way up slope.	Low	2.0	Vehicle spinning near 100% at crest of slope. Difficult "Go" test.		No Go	Vehicle im- mobilized 3/4 way up
	Low-2	6.3		Low-2	6.[illegible]	Vehicle negotiated slope with ease.	Low-1	4.0	Vehicle spinning near crest of slope.	Low-1	2.0	Difficult cle cut a of slope b pleting te
	Low-Low	5.1	Vehicle spinning up entire slope.	Low-Low	3.6	Vehicle Spinning up entire slope		No Go	Vehicle immobilized just past toe of slope.			

ary testing.

tests with these two vehicles several runs were made in several gear configurations to obtain an optimum gear for the best speed upslope. With the M274A2 and M151A2 table.

Table 10

Slope Tests at Vicksburg, Mississippi

Slope 2, 35%			Grassy Silt Slope 3, 40.3%			Grassy Silt Slope 4, 44.2%			Grassy Silt Slope 5, 53.5%		
ear	Speed, mph	Remarks	Range/Gear	Speed, mph	Remarks	Range/Gear	Speed, mph	Remarks	Range/Gear	Speed, mph	Remarks
	9.0	Vehicle showing slightly near crest	Low-2nd	7.5		Low-2nd	6.8		Low-1st	6.6	Some bounce and slip on slope
	8.8	Vehicle slowing slightly near crest	1st	10.4	Some wheel slip	1st	8.8	Some wheel slip	1st	6.6	Wheels slipping upper 1/2 of Slope
	8.5	Vehicle slowing slightly near crest		*			*			*	

culties and was not repaired in time for these tests.

	Slope 5 38.8%		Slope 6 46.0%			Slope 7 54.0%			Slope 8 58.0%		
	Speed, mph	Remarks	Gear	Speed, mph	Remarks	Gear	Speed, mph	Remarks	Gear	Speed, mph	Remarks
	5.9	Near 100% slip at crest but vehicle had sufficient power to complete test with wheels spinning.		No Go	Vehicle immobilized at toe of slope.						
	5.4	Some slip about 2/3 way up slope.	Low	2.0	Vehicle spinning near 100% at crest of slope. Difficult "Go" test.		No Go	Vehicle immobilized about 3/4 way up slope.			
2	6.3	Vehicle negotiated slope with ease.	Low-1	4.0	Vehicle spinning near crest of slope.	Low-1	2.0	Difficult "Go". Vehicle cut away crest of slope before completing test.		No Go	Vehicle t[illegible]eled 1/3 way up slope before imoilizing.
	3.6	Vehicle Spinning up entire slope		No Go	Vehicle immobilized just past toe of slope.						

several [illegible]ar [illegible]onfigurations to obtain an optimum gear for the best speed upslope. With the M274A2 and M151A2, the speeds were erratic in the same gear,

1

	Grassy Silt					
3%	Slope 4, 44.2%			Slope 5, 53.5%		
Remarks	Range/Gear	Speed, mph	Remarks	Range/Gear	Speed, mph	Remarks
	Low-2nd	6.8		Low-1st	6.6	Some bounce and slip on slope
Some wheel slip	1st	8.8	Some wheel slip	1st	5.[illegible]	Wheels slipping upper 1/2 of Slope
		*			*	

58<

Table 11

Summary of Drawbar-Pull Versus Slip Tests
Wheel/Track Convertible Test Rig
Laboratory Prepared Clay (CH) and Sand (SP)

Tracked Mode, 8x8, 15-RCI Sand

DBP, lb	D/W	Slip, %
556	0.08	2.9
777	0.12	3.5
1,213	0.18	4.5
1,959	0.29	10.2
2,098	0.31	14.7
2,149	0.32	24.6
2,225	0.33	36.2
2,427	0.36	49.9
2,793	0.42	64.9
3,185	0.48	76.8
3,451	0.52	87.4
4,171	0.63	≈100.0

Avg towed motion resistance, lb = 990

Tracked Mode, 8x4 15-RCI Sand

DBP, lb	D/W	Slip, %
700	0.10	3.8
1,062	0.16	6.4
1,770	0.27	8.9
2,073	0.31	9.5
2,402	0.36	21.4
2,477	0.37	27.1
2,680	0.40	37.9
3,059	0.46	54.5
3,198	0.48	65.7
3,324	0.50	78.3
3,615	0.54	87.5
4,095	0.61	≈100.0

Avg towed motion resistance, lb = 784

Tracked Mode, 8x8, 36-RCI Clay

DBP, lb	D/W	Slip, %
713	0.11	1.9
1,278	0.19	2.7
1,770	0.27	4.1
2,851	0.43	6.4
3,638	0.55	8.3
4,105	0.62	9.8
4,646	0.70	11.8

Avg towed motion resistance, lb = 1,279

Tracked Mode, 8x4, 36-RCI Clay

DBP, lb	D/W	Slip, %
635	0.10	3.0
927	0.14	3.4
1,574	0.24	5.1
1,980	0.30	5.9
2,488	0.37	6.1
3,225	0.48	6.7
3,885	0.58	9.0
4,723	0.71	13.0
1,473	0.22	5.0
2,514	0.38	6.2
3,529	0.53	8.2
4,570	0.69	11.5
5,078	0.76	15.6

Avg towed motion resistance, lb = 896

Wheeled Mode, 66-RCI Clay

DBP, lb	D/W	Slip, %
389	0.07	0.9
561	0.10	1.3
644	0.12	1.7
921	0.16	3.5
2,065	0.37	5.1
2,187	0.39	5.8
3,341	0.60	13.7
4,251	0.76	25.9
5,028	0.90	40.1
5,039	0.90	75.3
5,394	0.96	100.0

Avg towed motion resistance, lb = 449

Table 12

Mobility Index Computations for Self-Propelled Wheeled Vehicles in Fine-Grained Soils

Vehicle Wheel/Track Convertible Test Rig Weight 5600

Tire Description [illegible]6 x 12 - 12 TERRA TIRE

(1) Contact Pressure Factor = $\dfrac{\text{Gross weight, lb} \quad 5600}{\text{Tire width, in.} \; (13.4) \times \dfrac{\text{outside diam of tire, in.}}{2} \; \left(\dfrac{27.1}{2}\right) \times \text{No. of tires} \; (8)}$ = 3.86

WEIGHT RANGE (lb) $\left(\dfrac{\text{Cross Vehicle Wt (lb)}}{\text{No. Axles}}\right)$ $\dfrac{5600}{4}$ = 1400

WEIGHT RANGE (lb)	WEIGHT FACTOR EQUATIONS
<2000 ✓	$Y = 0.553X$
2000 to 13,500	$Y = 0.033X + 1.050$
13,501 to 20,000	$Y = 0.142X - 0.420$
>20,000	$Y = 0.278X - 3.115$

(2) Weight Factor =

$X = \dfrac{\text{Gross Vehicle Wt (kips)}}{\text{No. of Axles}}$ Y = Weight Factor = 0.77

(3) Tire Factor = $\dfrac{10 + \text{tire width, in.}}{100} = \dfrac{10 + 13.4}{100}$ = 0.234

(4) Grouser Factor = With chains = 1.05; Without chains = 1.00 ✓ = 1.00

(5) Wheel Load Factor = $\dfrac{\text{Gross weight, kips}}{\text{No. of wheels (Duals as one)}} = \dfrac{5.6}{8}$ = 0.7

(6) Clearance Factor = $\dfrac{\text{Clearance, in.}}{10} = \dfrac{14}{10}$ = 1.40

(7) Engine Factor = >10 hp/ton = 1.00; <10 hp/ton = 1.05 = 1.00

(8) Transmission Factor = Hydraulic = 1.00; Mechanical = 1.05 = 1.00

$$\text{Mobility Index} = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6)\right] \times (7) \times (8)$$

$$\text{Mobility Index} = \left[\frac{3.86 \times 0.77}{0.234 \times 1.0} + 0.7 - 1.4\right] \times 1.00 \times 1.00$$

Mobility Index = 12

Vehicle Cone Index$_1$ = 11

$VCI_1 = 11.48 + 0.2(12) - \dfrac{39.2}{12 + 3.74}$

$VCI_1 = 13.88 - 2.49 = 11.39$ or 11

(Continued) (1 of 2 sheets)

Table 12

(Concluded)

Vehicle Wheel/Track Convertible Test Rig Weight 6700

Track Description 15 1/4" wide 4.03" shoe [illegible] 37.2" [illegible]

$$\text{Mobility Index} = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6) \right] \times (7) \times (8)$$

(1)	Contact Pressure Factor	= Gross weight, lb / Area of tracks in contact with ground, sq in. = $\frac{6700}{[illegible] \times 15.25 \times 4}$	=	2 [illegible]
(2)	Weight Factor	: <50,000 lb = 1.0 ✓ 50,000 to 69,999 lb = 1.2 70,000 to 99,999 lb = 1.4 100,000 lb or > = 1.8	=	1.0
(3)	Track Factor	= Track width, in. / 100 = $\frac{15.25}{100}$	=	0.153
(4)	Grouser Factor	: <1.5 in. high = 1.0 ✓ >1.5 in. high = 1.1	=	1.0
(5)	Bogie Factor	= Gross wt ÷ 10 / Total no. bogies in contact with ground x area of 1 track shoe = $\frac{670}{8 \times 4.03 \times 15.25}$	=	1.36
(6)	Clearance Factor	= Clearance, in. / 10 = $\frac{17}{10}$	=	1.7
(7)	Engine Factor	= >10 hp/ton = 1.00 ✓ <10 hp/ton = 1.05	=	1.00
(8)	Transmission Factor	= Hydraulic = 1.00 ✓ Mechanical = 1.05	=	1.00

Mobility Index = $\left[\frac{[illegible] \times 1.0}{[illegible] \times 1.0} + 1.36 - 1.7\right] \times 1.00 \times 1.00$ = 18.9

VCI, = 9

VCI, [illegible] 18.9 − $\frac{39.2}{18.9 + 5.0}$

VCI = 0.78 [illegible] = 8.8 or 9

APPENDIX A
TEST PLAN FOR WHEEL/TRACK CONVERTIBLE
TEST RIG, 3/4-TON

Background

1. The Wheel/Track Convertible Test Rig, 3/4-Ton, is in response to USCDC Infantry Agency Draft Proposed Small Development Requirement, Tactical Infantry Load Carrier/TILCAR and USARAL DPSDR, Helicopter Transportable Cargo Carrier, Full Tracked, 1/2 ton (both requirements presently being rewritten in material need format). It could also be responsive to the USMC Specific Operational Requirement TM-4.5, Vehicle Utility 1/2 Ton Capacity, USAF Tactical Air Command Required Operational Capability 48-58, Improved Ground Vehicle for the Tactical Air Control System, and TVA-85 requirement for a 1/2-Ton Utility Vehicle.

2. This high mobility vehicle will provide a subsistence load-carrying capability for the foot soldier in the forward area, thus making available the protective equipment and other items of necessity while lessening the noncombat load required to be back-packed by the infantryman.

3. The short-range objective of this program is to provide the Army with a highly mobile existence load carrier. This, in turn, will provide significant technical information for the development of the high mobility fleet projected for Army-85. The initial test rig will be a one-man 8x8 skid-steer 3/4-Ton Carrier.

Status

4. This program was initiated in FY 70, at which time the Concept Design Phase was completed. During the first quarter of FY 71, TACOM

recommended and received approval from Hq, AMC, to begin detailed design of a Wheel/Track Convertible Test Rig that would be based on the concept that evolved from the FY 69-70 parametric concept design phase. Subsequently, in FY 71, the engineering design of the major subsystems was completed. This included the hull, engine, power train and final drive, cooling system, powered road arms, and friction-driven track.

5. The Test Rig is presently being fabricated in-house by TACOM and is scheduled for completion in the third quarter FY 72. It will be powered by the M151 Ford L141 four-cylinder engine, the XM501E3 Hawk Loader automatic transmission, and a differential steer unit. Its final drive will consist of powered road arms coupled to the steer unit through a gear drive system. Testing of this configuration will be initiated in FY 72.

Objective

6. The overall objective of the test plan is to evaluate the unique suspension and wheel/track convertible features that are considered the high risk/high return areas namely the track, suspension and handling characteristics and to determine military potential of the Test Rig. The overall objectives of the test plan are to: (a) evaluate wheel/track interface under varying surface and terrain conditions, (b) select optimum suspension characteristics, (c) determine handling characteristics.

Scope

7. This test plan was designed to provide sufficient quantitative performance-type data to objectively assess the feasibility of the

wheel/track convertible concept and its unique suspension at the Exploratory Development Phase of the life cycle of the vehicle. This objective will be sought through the application of ground mobility technology developed by TACOM and WES Laboratories. Thus, specific relations that account for pertinent terrain, vehicle, driver interactions required for an objective vehicle evaluation were included in the test plan along with the appropriate data collection and analysis procedures. The type and number of tests required are minimal, and existing data for comparative vehicle performance will be utilized to the maximum in achieving the test plan objectives.

Test Vehicles

8. The test vehicles that will be used in this program are the: Wheel/Track Convertible Test Rig, 3/4-Ton; M274A2, 4x4, 1/2-Ton Truck; M151A1, 4x4, 1/4-Ton Truck; and the M116, 1/2-Ton Tracked Cargo Carrier. The latter three vehicles will be used in comparative analyses when considered necessary. Special devices such as roll bars and seat belts will be adapted to the test vehicles as required to provide driver safety. A sketch of the Test Rig and pertinent characteristics are shown in fig. A1. Photographs of vehicles that will be used in comparative analyses are given in fig. A2. A comparison of Test Rig and military vehicle characteristics is shown in table A1.

Test Areas

9. Field tests will be conducted at Keweenaw Field Station, Houghton, Mich., and at Ft. Sill, Oklahoma, Vicksburg, Mississippi, and Yuma Test Station, Yuma, Arizona. Laboratory tests will be conducted at TACOM and WES.

VEHICLE CHARACTERISTICS

ENGINE	[illegible] JEEP, WATER COOLED, GASOLINE
TRANSMISSION	FORD 3 SPEED AUTOMATIC
CROSS DRIVE	BOWEN, [illegible]
SUSPENSION	INDEPENDENT, TORSILASTIC
WEIGHT NET	[illegible] LBS, STEEL HULL
WEIGHT GROSS	[illegible] LBS, STEEL HULL
GROUNDPRESSURE	[illegible] PSI WHEEL, 2.7 TRACK
FLOTATION	[illegible] INCH FREEBOARD TO DECK
RANGE (25 GAL. FUEL)	250 MILES
SPEED RANGE	0-40 MPH
HORSEPOWER / TON	26
VEHICLE CONE INDEX	[illegible] WHEEL, 20 TRACK
CARGO AREA	26 SQ. FT.
L/T	[illegible]
TRANSPORTABILITY	PHASE I AIRCRAFT, STACKABLE

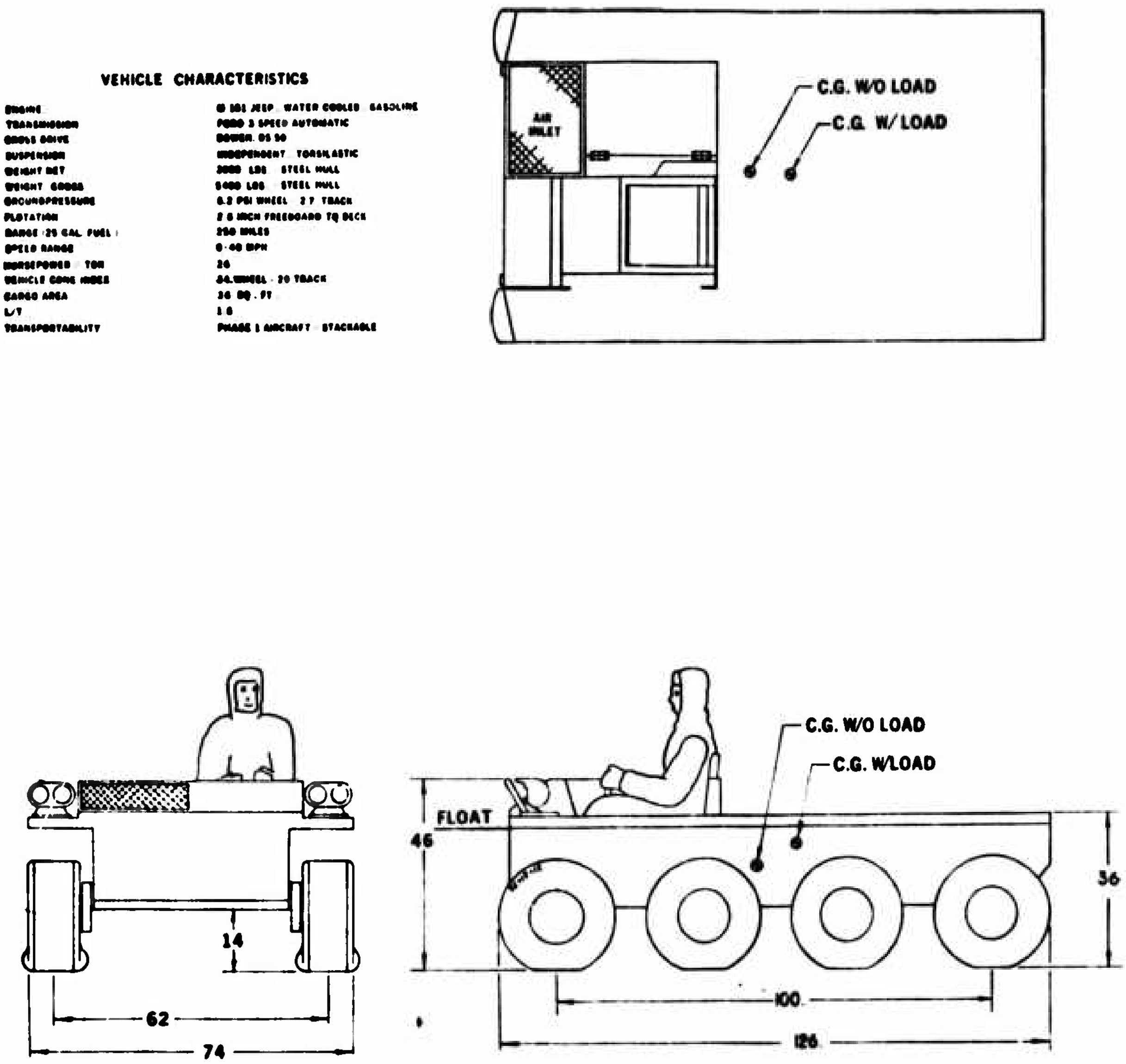
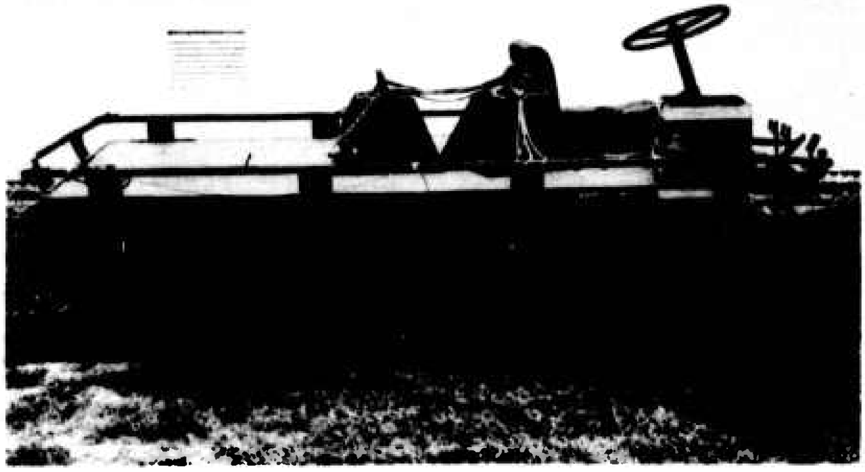
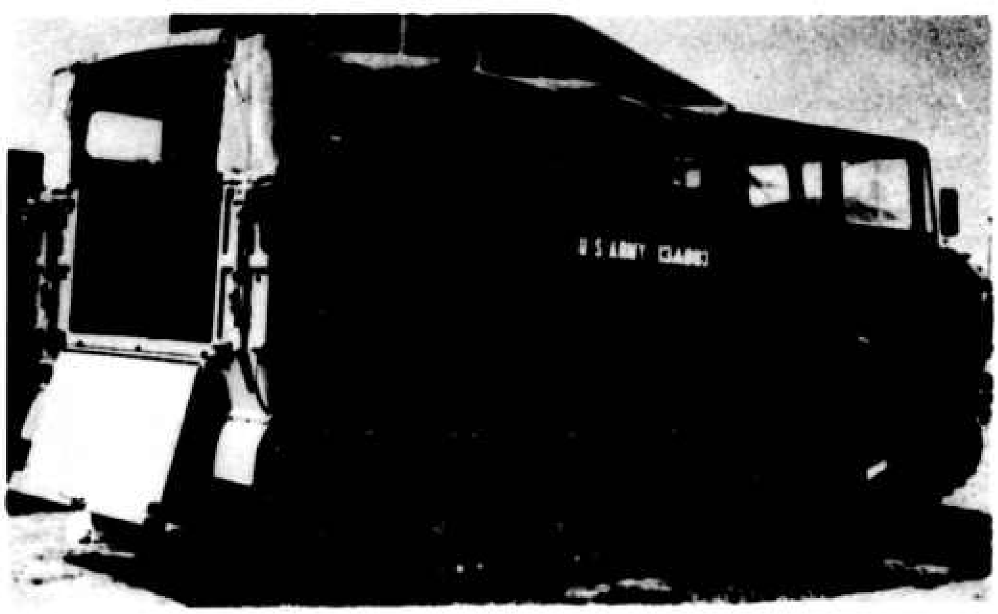


Fig. A1. Field/Track Convertible Test Rig



a. M274A2, 4x4, 1/2-ton truck

b. M151A1, 4x4, 1/4-ton truck



c. M116, 1-1/2-ton cargo carrier

Fig. A2. Vehicles to be used in comparative performance analysis

Test Program

10. The test program was designed to achieve the overall objectives identified in paragraph 6. The test activities included in the test program, listed in chronological order, are: shakedown tests, track tests, suspension tests, handling tests, and dynamic response field evaluation tests. All test activities were considered on the basis of type of test, location of test area in which the desired test condition can be found, data to be collected, results to be achieved, responsible agency, time required, and a cost estimate for each type of test. Details of the test activities are given in tables A4, A6, A7, A8 and A9. A memorandum report will be prepared and it will include a description of the tests and a discussion of test results of all test activities.

11. In all test activities, sufficient terrain, vehicle, driver response data will be collected to answer in quantitative terms the questions asked in each specific test activity. The terrain, vehicle, driver relations, testing techniques, and data collection procedures developed under the AMC ground mobility research programs will be used. In addition to the test activities identified herein, a daily log book will be maintained in which system failures, mileage and other data will be recorded from which conventional reliability and maintainability parameters can be obtained for comparative purposes. Photography will be used as an aid in describing terrain conditions tested and pertinent vehicle response. Measurement of fuel consumption will be made where applicable.

12. The specific test activities included in the test program are discussed in the following paragraphs.

67<

Shakedown tests (table A4)

13. Upon completion of Test Rig fabrication, shakedown tests will be conducted by TACOM at TACOM. The type of tests will include functional checkout, characteristic measurements, and break-in runs. The functional checkout will involve a preoperational inspection to ensure that the test vehicle is in proper functional condition for testing purposes. Physical and mechanical characteristic measurements will be made to permit making a variety of performance analyses in keeping with the AMC 71 mobility model. The specific measurements to be made are listed in table A2. Break-in runs scheduled will further ensure the readiness of the Test Rig for field testing. The Test Rig will be run 16 hours in the wheel configuration on primary roads and 8 hours in the track configuration on secondary, unpaved roads. During these runs fuel consumption rates will be determined. A summary of the test activity, including the test variables and terrain conditions, is given in table A4. The log book documentation will be initiated with this activity and continued throughout the program.

14. The Test Rig will be provided with a simulated design payload corresponding to the average military cargo. In the track configuration, tire pressure will be varied to determine the relationship between tire pressure and track tension. Also, the ranges of track tension and tire pressures to be used in the follow-on tests will be established. During the shakedown tests, the specific wheels on which positive drive devices (sprockets) are to be installed will be determined. The results of these data will be used to prepare the Test Rig for testing operations.

Track tests (table A6)

15. These tests were designed primarily to evaluate the feasibility of the wheel/track convertible concept to determine if the track stays on, if it slips and if it causes any durability or performance problems. The tests will be conducted jointly by TACOM and WES at Houghton, Mich., and Vicksburg, Miss., upon completion of the shake-down tests. This part of the test program includes roads (primary and secondary), trail, cross-country under varying terrain conditions and special soil type tests.

16. Road and trail tests at Houghton will be the first type of test conducted. These surface media will have various combinations of slope, microgeometry, curves and surface conditions. The trails selected for testing will be described and measurements will be made according to WES techniques and the factors to be used in describing the trails are given in the first column of table A5. The data also include measurement of the trail profile elevation. The Test Rig will be tested in the track and wheel configurations with the design payload. The track configuration will first be tested in friction drive, and it will also be tested in the positive drive mode (sprocket). In addition to terrain data, time and distance measurements will be made for computing average speed. Driver response will be recorded to indicate vehicle stability and handling. The sections of the trail or features on the trail that require high traction demands for the vehicle to negotiate will be selected to observe the interaction between the wheel and track especially track slippage, track throwing, soil build-up and judgement of performance. Movies of these observations will be made. Attempts will be made to maintain constant ground pressure distribution in both wheeled and tracked modes.

17. Cross-country traverse tests will be conducted at Houghton, Mich., and these tests will provide terrain conditions not commonly found on trails. For example, tests will be conducted in woody areas where variations in stem size, spacing, macrogeometry obstacles and vertical steps such as dead fall can be found. The test variables, data to be collected, and results expected are the same as for the trail test discussed in the previous paragraph.

18. The special soil type tests were included to ensure that the performance of the Test Rig in its wheel/track configuration will be satisfactory when operating in various soft surface media since these conditions place the greatest demands on vehicle traction elements. To obtain the necessary soft snow, organic, and fine-grained soil conditions, tests will be conducted at Houghton and Vicksburg. In each of these media, uniform areas will be selected for test purposes. For each type of surface media, tests will be run at three or four strengths to relate performance to strength of the media, or in case of snow, to snow depth. Vehicle operations will include straight line (directional) and turning maneuvers in both cross-country and soft soils tests. The test variables will include wheel/track configuration with friction and positive drives at the design payload. First-pass relations between strength and maximum drawbar pull-slip and rolling resistance will be established for fine-grained and organic soils. For snow, a relation between snow depth of fine-grained, dry snow and drawbar pull-slip and rolling resistance will be developed. In fine-grained and organic soil, tests will be run at strengths ranging from above the one-pass vehicle cone

index (minimum soil strength required) to about 50 points above the minimum requirement. Pertinent observations will be recorded, and movies will be made of the wheel/track interaction in the test media. Special attention will be given to the amount of material built up on the running gear of the vehicle.

19. Special laboratory tests will be conducted by WES with the Test Rig in the wheel/track configuration at Vicksburg in heavy clay soils prepared to the consistencies discussed in the previous paragraph and with surface conditions ranging from flooded to soft mud to determine the performance of the wheel/track convertible concept in these types of surface conditions. The test variables will be friction and positive track drives. The Test Rig will be tested at design payload and at predetermined track tensions. Drawbar pull-slip and rolling resistance tests will be conducted to establish optimum track tension. For each test condition, the amount of soil build-up for various levels of traffic will be determined by weighing the vehicle before and after specific test runs. Similar tests will be run with the comparison vehicles.

20. A summary of the track tests is given in table A6, and the indoor facility to be used in the test program is shown in fig. A3.

Suspension tests (table A7)

21. Suspension tests will be conducted to optimize the Test Rig suspension system within allowable constraints. Drop and discrete obstacle tests will be conducted by TACOM at TACOM. The maximum step height that the Test Rig can negotiate will be determined using paved surface and rigid obstacles.

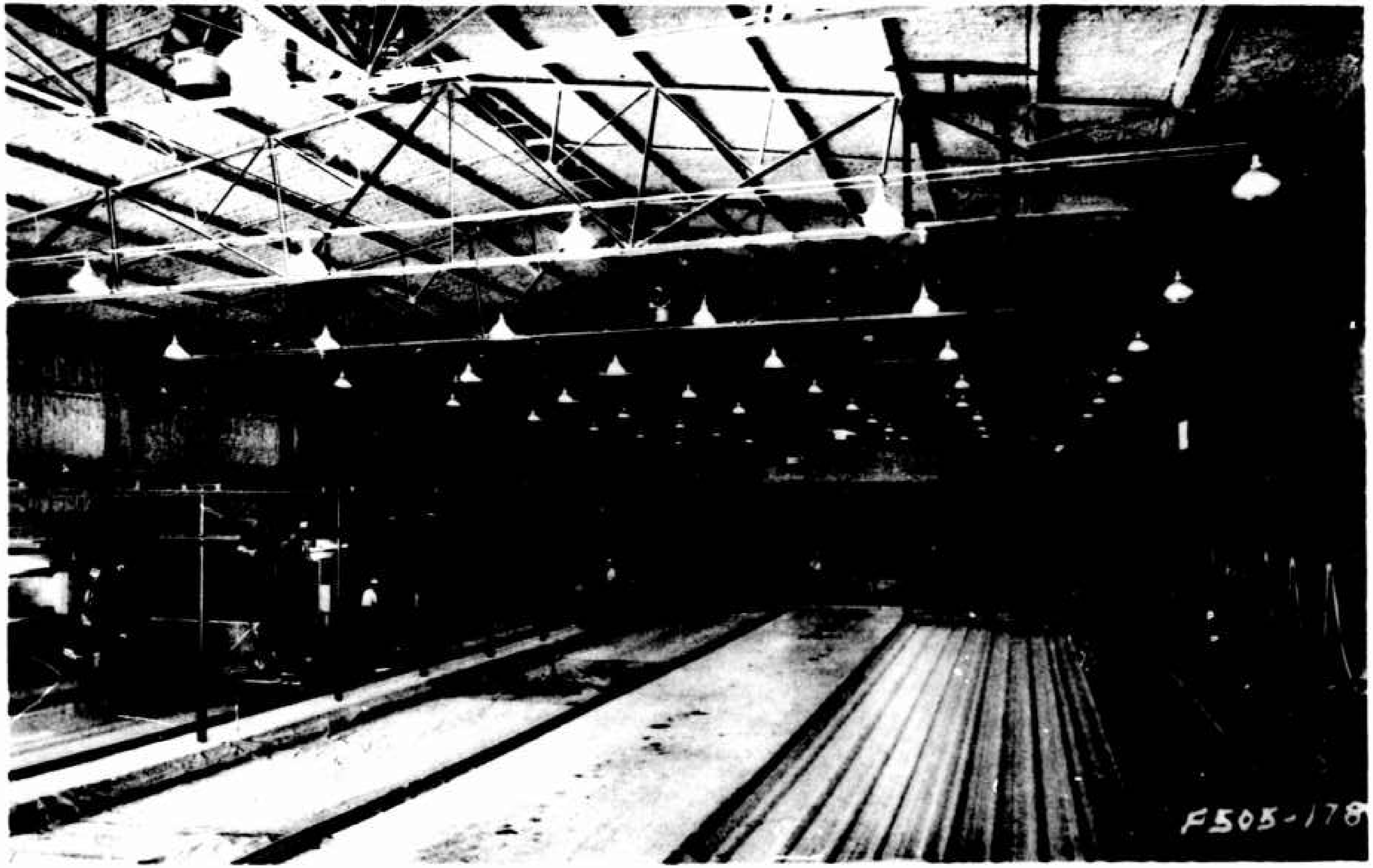


Fig. A3. WES large test facility

22. In the drop tests, the Test Rig will be dropped in the track and wheel configurations. The track configuration will include the friction and positive drive modes as previously determined in the track tests, also track tension will be constant as predetermined. All configurations will be dropped with and without payload. The variables will include tire pressure, suspension damping rate, spring rate, and wheel travel. The last three variables will be varied within allowable limits.

23. Discrete obstacle tests will be conducted to characterize the Test Rig suspension system in terms of obstacle height, speed, peak vertical acceleration relations. Tests will be run over ramped cross section, discrete, rigid obstacles fixed on a hard, level surface. Obstacle height will be varied from 2 to 12 in. Operations will be conducted at 3-mph increments to maximum safe speed. Failure criteria include hull pitch in excess of 20 degrees total (peak to peak) and/or peak vertical accelerations in excess of 2 g's for a period in excess of 10 milliseconds. The Test Rig will be tested in the same configurations as the drop tests. In addition to the data to be collected for the drop tests, the discrete obstacle tests will include damper temperature, vehicle speed, obstacle height, vehicle pitch and roll amplitude, vertical acceleration at CG, and vehicle pitch and roll accelerations, road arm displacements and loads. A summary of the test activity is given in table A7.

Handling tests (table A8)

24. These tests were included in the test program to gain preliminary assessment of the dynamic stability and the handling characteristics

of the 8X8 powered trailing arm, ratio/skid steer Test Rig in the wheel mode only. Particular emphasis will be given to the determination as to whether or not the Test Rig exhibits over/under steer characteristics when executing different rates of directional changes. These tests will be conducted by TACOM at the Raco, Michigan, airport. Test courses will be laid out on level, paved surfaces.

25. The types of tests planned include a slalom, constant radius, lane change, and sudden right angle turn. The Test Rig will be tested with and without payload, and at one tire pressure. In the slalom test, the Test Rig will be operated at several constant speeds to determine the spacing of stakes laid out in a straight line that the vehicle can maneuver around safely. Constant radius, lane change, and sudden right angle turn tests will be run at several speeds. The data to be collected will be the same for all types of tests, and they include measurements of vehicle speed, angular velocity, lateral acceleration, braking distance, driver comments and observation notes. Movie coverage will be provided during all phases of the handling tests. The results of these tests will be used to evaluate maneuverability and to determine whether or not the Test Rig exhibits dynamic instabilities. If the latter is true, a determination will be made as to the type of maneuver and speed at which these characteristics are exhibited. Similar data available for the M151A2 will be used in making a comparative handling evaluation. A summary of the test activity is given in table A8.

Dynamic response field evaluation test (table A9)

26. In order to gain some insight as to the dynamic response capabilities of the Test Rig over a variety of natural terrain conditions,

cross-country and ride tests will be conducted by WES and TACOM at Ft. Sill, Yuma Proving Ground, and Vicksburg over test courses for which terrain and performance data for several vehicles (M48A1, M113A3, M151A1, M35A2 mod) are available. The courses have been staked out and described recently for ground mobility purposes under other test programs. Only those terrain factors that exhibit temporal changes (e.g., soil strength) will require remeasurement.

27. Cross-country tests will be conducted with the Test Rig in track and wheel modes with the design payload. Prior testing will determine whether friction or positive drive will be used. Tests in the wheel mode will be run at one tire pressure at Ft. Sill and at two tire pressures at Yuma. Three or four courses varying in length from about 1 to 3 miles will be tested at each location. Data collection will be similar to suspension tests and will include time and distance.

28. The ride tests scheduled will be conducted by TACOM at Ft. Sill and Vicksburg with the same Test Rig variables as indicated in the above paragraph for the cross-country tests. Testing will be restricted to three level, firm, natural terrain test courses that have desired differences in root mean square (rms) elevation. At each test course, the Test Rig will be run at three or four different speeds. The data collected will be similar to that of the suspension tests. These data will be used to compute ride quality and these values will be used to compare ride with other vehicles previously tested over the same courses. A summary of test activities is given in table A9.

Report

29. A memorandum report will be prepared at the end of the test program in which the tests and the results will be described. To expedite preparation of a final report, draft reports on each test activity will be prepared as soon as completed.

Test Schedule and Cost

30. A test schedule based on the number of test days and cost for each test activity is given in table A10, and a time schedule and cost for each test activity are summarized in table A11. A total of 150 working days are required and the total cost of the program is estimated at $100,000.

Table A1
Comparison of Test Rig and Military Vehicle Characteristics

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
				[illegible]	[illegible]	[illegible]	[illegible]
CURB WT - LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CREW - LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PAYLOAD - LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GROSS WT - LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LENGTH - IN	[illegible]	132	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WIDTH - IN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HEIGHT - IN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CARGO PLATFORM HEIGHT - IN	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AREA - SQ FT	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LENGTH - IN	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WIDTH - IN	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LONGITUDINAL SLOPE - %	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SIDE SLOPE - %	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MAX SPEED - MPH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MIN SPEED - MPH	1	2.5	2.5	1	1	1	1
ANGLE OF APPROACH - °	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ANGLE OF DEPARTURE - °	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RAMP ANGLE - °	[illegible]	[illegible]	--	[illegible]	—	[illegible]	--
GROUND CLEARANCE - IN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VERTICAL STEP - IN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TIRE SIZE	[illegible]	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]
RIM DIAMETER - IN	[illegible]	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]
WHEEL/TRACK WIDTH - IN	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GROUND PRESSURE - PSI	[illegible]	7.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VCI 50 PASS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VCI 1 PASS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MOBILITY INDEX	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TURNING RADIUS - FT	[illegible]	[illegible]	PIVOT [illegible]	[illegible]	[illegible]	PIVOT	PIVOT
L/T RATIO	—	--	1.0	1.6	1.6	1.7	1.7
TYPE STEERING	2 WHEEL ACKERMANN	2 WHEEL ACKERMANN	DIFF & CLUTCH/BRAKE	DIFF [illegible]	DIFF [illegible]	INFINITE VARIABLE	INFINITE VARIABLE
HP (NET)	[illegible]	[illegible]	[illegible]	70	70	[illegible]	[illegible]
POWER/WT RATIO HP/TON	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TYPE SUSPENSION	NONE	INDEPENDENT COIL SPRING	TORSION BAR	INDEP TRAILING ARM/ TORSILASTIC	INDEP TRL'G ARM/ TORSILASTIC	INDEP TRL'G ARM/ TORSILASTIC	INDEP TRL'G ARM/ TORSILASTIC
WHEEL TRAVEL - IN FRONT	0	[illegible]	± 6¾, − 3	[illegible]	[illegible]	[illegible]	[illegible]
REAR	0	[illegible]	± 6¾, − 3	[illegible]	[illegible]	[illegible]	[illegible]
ARTICULATION	NONE	NONE	NONE	NONE	NONE	NONE	NONE
TYPE TRANSMISSION	3 SPEED MANUAL	4 SPEED MANUAL	3 SPEED AUTOMATIC	3 SPEED AUTOMATIC	3 SPEED AUTOMATIC	HYDRO-MECHANICAL INF VAR	HYDRO-MECHANICAL INF VAR
SWIM SPEED - MPH	NONE	NONE	[illegible]	FLOAT	FLOAT	FLOAT [illegible]	FLOAT [illegible]

Table A2

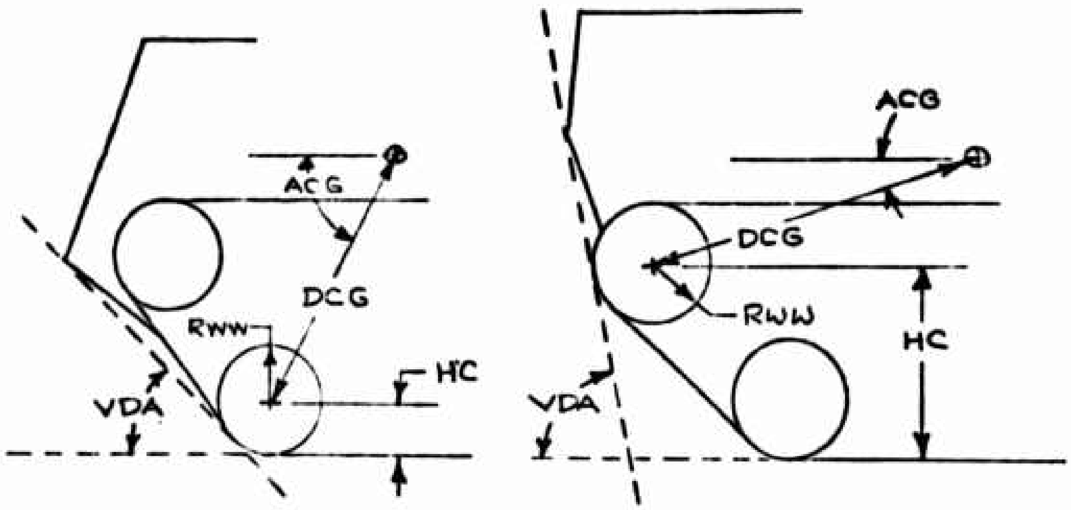
Vehicle Data Required for AMC 71 Mobility Model

Variable Name	Definition	
NVEH	Vehicle type Tracked = 0 4X4 = 1 6X6 = 2 8X8 = 3	______
ITRAN	Transmission type stick = 0 automatic = 1	______
GVW	Gross vehicle weight (lb)	______
DL	Tracked: Length of track on ground (in.) Wheeled: Wheel diameter (in.)	______
WID	Track or wheel width (in.)	______
GT	Tracked: Grouser height (in.) Wheeled: Number of tires	______
A	Tracked: Area of one track shoe (sq. in.) Wheeled: Number of axles	______
HPT	Rated horsepower per ton	______
GC	Ground clearance at the center of the greatest wheel span (in.)	______
NBC	Tracked: Number of bogies Wheeled: Denotes presence of chains - no = 0 yes = 1	______
ITVAR	Transmission variety hydraulic = 0 mechanical = 1	______

(1 of 8 sheets)

Table A2 (Continued)

Variable Name	Definition	
TL	Distance between first and last wheel centerlines (in.)	______
FEC	Front end clearance (in.) (Vertical clearance of vehicles' leading edge)	______
VAA	Approach angle (deg)	______
REC	Rear end clearance (in.)	______
VDA	Departure angle (deg.)	______
CGF	Horizontal distance from the CG to the front wheel centerline (in.)	______
CG	Vertical distance from the CG to the roadwheel centerline (in.)	______
GWS	Maximum span between adjacent wheel centerlines (in.)	______
RW	Tracked: Roadwheel radius plus track thickness (in.) Wheeled: Tire rolling radius (in.)	______



The following four variables relate to the wheel (roadwheel or idler) which is used to determine departure angle (see figures).

ACG	Angle between a line parallel to the ground and the line connecting the CG and the wheel center (deg.)	______
DCG	Distance from the CG to the wheel center (in.)	______
HC	Vertical distance from the wheel center to the ground (in.)	______
RWW	Wheel radius plus track thickness (in.)	______
HS	Maximum vertical step that the vehicle can climb (in.)	______
WC	Winch capacity (lb)	______
SAI	Ingress swamp angle (deg.)	______

AWPFR	Auxilliary water propulsion factor (propeller, water-jet, etc) - no = .5 yes = .8	______________
GCA	Ground contact area (sq. in.)	______________
FD	Fording depth or draft height (in.)	______________
VSS	Swimming speed (mph)	______________
VFS	Fording speed (mph)	______________
NCREW	Number of people in the vehicle on a normal mission.	______________
NFL	Track type - flexible = 1 non - flexible = 0	______________
Wheels only:		
RDIAM	Wheel rim diameter (in.)	______________
TPS	Tire pressure (psi)	______________
TPLY	Tire ply rating	______________
W	Vehicle width (in.)	______________
PBHT	Pushbar height (in.)	______________
PBF	Maximum force that the pushbar can withstand (lb)	______________
VL	Vehicle length (in.)	______________
XBR	Maximum braking force that the vehicle can develop (lb)	______________
RR	Tracked: Sprocket pitch radius (in.) Wheeled: Tire rolling radius (in.)	______________
FDR	Final drive gear ratio	______________

(4 of 8 sheets)

EFF	Transmission efficiency	______
FDREF	Final drive efficiency	______
NG	Number of transmission gear ratios	______
GR(I)	Transmission gear ratios	______

VØØB(I,J) The velocity, in travelling over vertical obstacles, which produces, 2 1/2 G vertical acceleration at the drivers' seat (5 to 20 pairs of values).

Obstacle Height (in)	Velocity (mph)

(5 of 8 sheets)

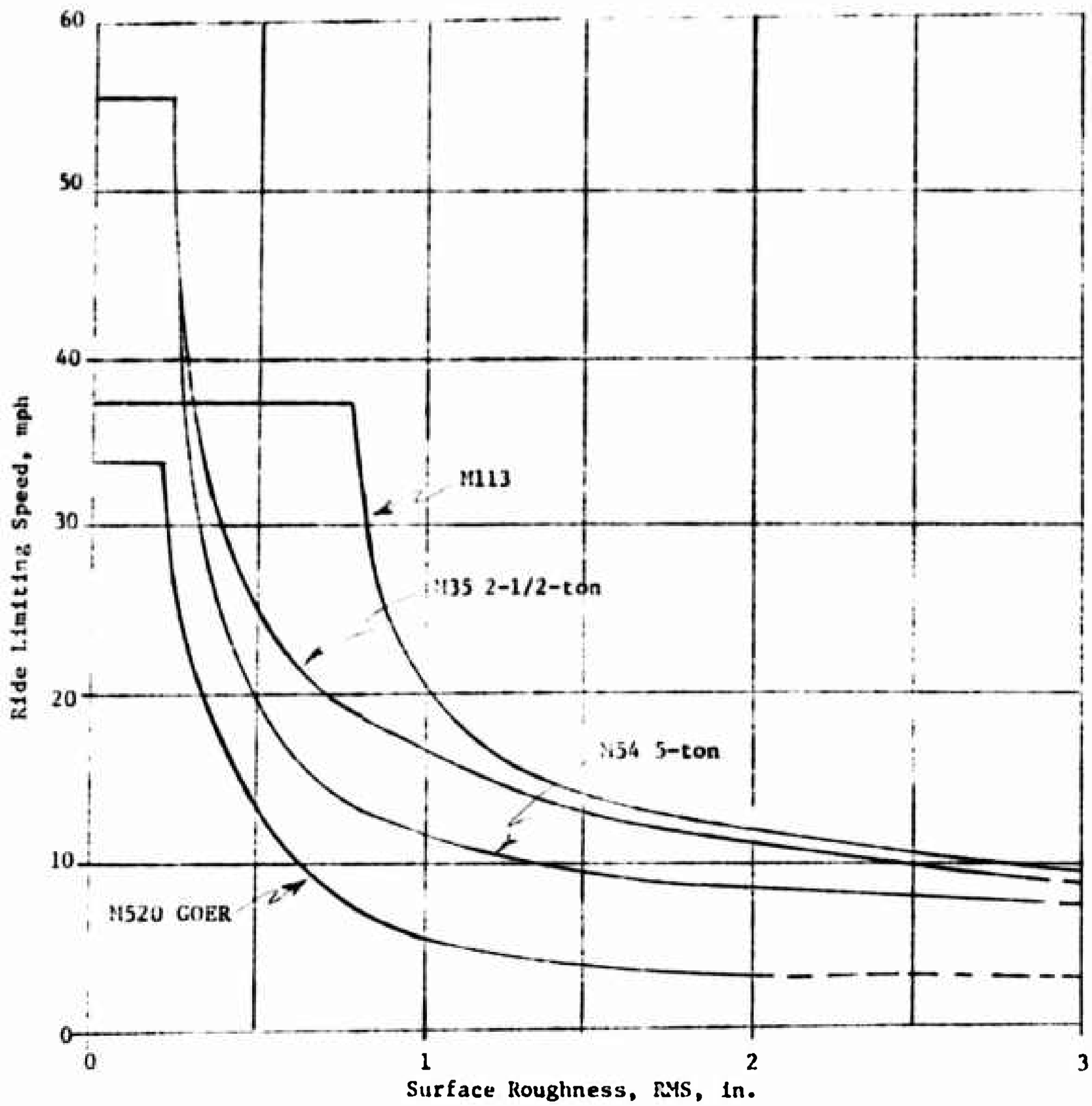
Table A2 (Continued)

VRIDE (I) Limiting speed due to vibration at the drivers' seat for surface roughness class I. (6 watts absorbed power)

Roughness Class	RMS Elevation (in.)	Limiting Speed (mph)
1	0.25	
2	1.	
3	2.	
4	3.	
5	4.	
6	5.	
7	6.	
8	7.	
9	8.	

Consult the attached graph to approximate these values. If more accuracy is required, the absorbed power calculation has been programmed and is available.

Table A2 (Continued)



RIDE DYNAMICS CHARACTERISTICS
OF
FOUR MILITARY VEHICLES

NOTE: Curves based on existing data (7 Nov 73)

(7 of 8 sheets)

Table A2 (Concluded)

TTE(I,J) Net engine torque versus engine speed curve. (10 to 20 pairs of values). Include maximum and minimum engine speed.

Engine Speed (RPM)	Net Engine Torque (ft. lb.)

The following are required for a vehicle with a torque converter.

TC	Input torque at which the torque-converter curves were measured (ft. lb.)	________
ENTCG	Gear ratio between engine and torque-converter (if present)	________
LØKUP	Denotes presence of a torque-converter lock-up. no = 0 yes = 1	________
TWE1(I,J)	Converter input speed versus speed ratio curve. (10 to 20 pairs of values)	________

Speed Ratio	Input Speed (RPM)

TTM(I,J) Converter torque multiplying coefficient versus speed ratio curve (10 to 20 pairs of values)

Speed Ratio	Torque Multiplying Coefficient

Table A3

Legend for Test Variables Given in Table A4 and Tables A6-A9

Description	Dimension	Symbol
Running gear configuration - wheeled	NA	w
Running gear configuration - tracked	NA	t
Vehicle weight (loaded or unloaded)	lb	W
Suspension damping rate	lb sec/ft	c
Suspension spring rate	lb/ft	k
Suspension wheel travel	in.	z
Track tension	lb	T
Friction drive between wheel and track	NA	t_f
Positive drive (sprocket) between wheel and track	NA	t_p
Vehicle unloaded	NA	u
Vehicle loaded	NA	l
Tire pressure	psi	T_p
Ground contact pressure	psi	p
Vehicle speed	mph	v
Obstacle height	in.	o

Table A4

Shakedown Tests

Type of Test	Location	Test Variables and/or Test Conditions*	Data to be Collected	Results	Respon-sible Agency	Schedule (Work Days)	Cost (New Money)
Functional Checkout	TACOM	NA	Record of adjustments	Log of adjustments	TACOM	1-2	0**
Characteristic Measurements	TACOM	t, w, p, W, c, k, z, T, u, l	Physical, mechanical	Establish relations pertinent to dynamic vehicle response and t/w interface friction	TACOM	3-6	0
Break-in Runs	TACOM	w-16 hr t-8 hr	Observation notes. Record of adjustments and fuel consumption.	Summary of notes, fuel consumption rate	TACOM	7-10	0

* See table A3 for legend.
** Previously authorized funds to be used.

Table A5

DESCRIPTION OF AREAL TERRAIN FACTOR CLASS NUMBERS

TERRAIN FACTORS	Class Numbers													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SURFACE TYPE	Fine Grained Soils	Coarse Grained Soils	Muskeg	New Permanent Snow	Permanent Snow							Snow		
* SURFACE STRENGTH (CI or RCI) CLASS RANGE	>280	221-280	161-220	101-160	61-100	41-60	33-40	26-32	17-25	11-16	0-10	13-25	7-12	0-6
VALUE SELECTED FOR PREDICTION	>300	250	190	130	80	50	36	29	20	14	5	19	10	3
SLOPE(%) CLASS RANGE	>0-2	2.1-5	5.1-10	10.1-20	20.1-40	40.1-60	60.1-70	>70						
VALUE SELECTED FOR PREDICTION	1	3.5	7.5	15.0	30.0	50.0	65.0	72.0						
OBSTACLE APPROACH ANGLE (Deg.) CLASS RANGE	178.6-180	180-181.5	175.6-178.5	181.5-184.5	170.1-175.5	184.5-190	158.1-170	190.1-202	149.1-158	202.1-211	135.1-149	211.1-225	90.0-135	226-270
VALUE SELECTED FOR PREDICTION	179	181	177	183	173	187	164	196	154	206	142	218	112	248
OBSTACLE VERTICAL MAGNITUDE (cm) CLASS RANGE	0-15	16-25	26-35	36-45	46-60	60-85	>85							
VALUE SELECTED FOR PREDICTION	8	20	30	40	52	72	85							
OBSTACLE BASE WIDTH (cm) CLASS RANGE	>120	91-120	61-90	31-60	0-30									
VALUE SELECTED FOR PREDICTION	360	105	75	45	15									
OBSTACLE LENGTH (m) CLASS RANGE	0-.3	.4-1.0	1.1-2.0	2.1-3.0	3.1-6.0	6.1-150	>150							
VALUE SELECTED FOR PREDICTION	.2	.6	1.5	2.5	4.5	78	150							
OBSTACLE SPACING (m) CLASS RANGE	Bare	20.1-60	11.1-20	8.1-11	5.6-8	4.1-5.5	2.6-4.0	0-2.5						
VALUE SELECTED FOR PREDICTION	60	40	15.5	9.5	6.8	4.8	3.3	1.2						
OBSTACLE SPACING TYPE	Random	Linear												
SURFACE ROUGHNESS (RMS Elev, in.) CLASS RANGE	0-.4	.5-1.5	1.6-2.5	2.6-3.5	3.6-4.5	4.6-5.5	5.6-6.5	6.6-7.5	>7.6					
VALUE SELECTED FOR PREDICTION	.2	1	2	3	4	5	6	7	8					
STEM DIAMETER (cm)	0	>2.5	>6.0	>10	>14	>18	>22	>25						
FACTOR VALUE	0	3	6	10	14	18	22	25						
STEM SPACING (m) CLASS RANGE	Bare	>20	11.1-20	8.1-11	5.6-8	4.1-5.5	2.6-4	0-2.5						
VALUE SELECTED FOR PREDICTION	100	20	15.5	9.5	6.8	4.8	3.3	1.2						
VISIBILITY (m) CLASS RANGE	>50	24.1-50	12.1-24	9.1-12	6.1-9	4.6-6	3.1-4.5	1.6-3.0	0-1.5					
VALUE SELECTED FOR PREDICTION	50	37	18	10.6	7.5	5.3	3.8	2.3	.8					
SNOW DEPTH (cm) CLASS RANGE	2.5-30.5	30.6-45.7	45.8-61.0	61.1-76.2	76.3-91.4	91.5-121.9	122.0-152.5	152.6-182.9	>182.9					
VALUE SELECTED FOR PREDICTION	16.5	38.2	53.4	68.6	83.8	106.7	137.2	167.8	182.9					
SNOW MOISTURE CONDITION	Dry	Wet												

* Surface strength for dry, average, and wet seasons

Table A6

Track Tests

Type of Test	Location	Test Variables and/or Test Conditions*	Data to be Collected	Results	Responsible Agency	Schedule	Cost TACOM/WES
Trail	Houghton	Trails having various combinations of slope, microgeometry, and surface conditions t_f, t_p, w, l, v	Average speed, observation notes, terrain factors, driver comments	Comparative speed performance evaluation	TACOM and WES	11-24	$10000 / $5000
Cross-country traverse	Houghton	Same as trail--with additional terrain variation	Same as trail	Same as trail	TACOM and WES	25-37	$ 7000 / $3000
Special terrain conditions	Houghton and Vicksburg	Snow, organic soil, fine-grained soil t_f, t_p, l	Observation of w/t interaction, max DBP, motion resistance, type and strength of surface media	Establish pertinent relations such as surface media strength-DBP-motion resistance relations	TACOM and WES	38-56	$10000/$15000
					Totals	46 days	$50,000

* See table A3 for legend.

Table A7

Suspension Tests

Type of Test	Location	Test Variables and/or Test Conditions*	Data to be Collected	Results	Responsible Agency	Schedule	Cost
Drop	TACOM	t, w, u, l, T_p, t_f, t_p, vary c, k, z within allowable limits; vehicle dropped on firm, level surface	Road arm load and position at station 1, 2, and 4 on left side of vehicle, frequency and damping of vehicle oscillation, spring damping rate of compliance elements, and observation notes	Establish vehicle dynamic characteristics from frequency and damping of vehicle oscillation and spring and damping rates of compliance elements within allowable constraints. Tune dynamic mathematical simulation model.	TACOM	57-87	$12,000
Discrete Obstacles	TACOM	t, w, t_f, t_p, u, l, o, v, T_p; vary c, k, z within allowable limits; rigid, ramped cross-section obstacles placed on level, firm surface	In addition to drop test data, damper temperatures, vehicle speed obstacle height, vehicle pitch and roll amplitudes, vertical acceleration at CG, vehicle pitch and roll acceleration as well as suspension displacement and load will be measured. Driver comments will be recorded.	Establish obstacle height, speed, vertical acceleration relations. Compare dynamic performance with other vehicles	TACOM	88-98	$ 8,000
					Totals	42 days	$20,000

* See table A3 for legend.

Table A8

Handling Tests

Type of Test	Location	Test Variables and/or Test Conditions*	Data to be Collected	Results	Responsible Agency	Schedule	Cost
Slalom	Raco, Mich.	v, u, l, v, Paved runway	Speed, angular velocity, lateral acceleration, driver comments, observation notes	Evaluation of handling characteristics	TACOM	99-100	$1000
Constant Radius	Raco, Mich.	v, u, l, T_p, v Paved runway	Same as slalom test	Establish over/under steer characteristics	TACOM	101-103	$1500
Lane Change	Raco, Mich.	v, u, l, v Paved runway	Same as slalom test	Establish if over/under steer is critical from handling standpoint	TACOM	104-106	$1500
Sudden Right Angle Turn	Raco, Mich.	v, u, l, v Paved runway	Same as slalom test	Same as lane change	TACOM	107-108	$1000
					Totals	10 days	$5,000

* See table A3 for legend.

Table A9

Dynamic Response Field Evaluation Tests

Type of Test	Location	Test Variables and/or Test Conditions*	Data to be Collected	Results	Responsible Agency	Schedule	Cost
Cross-country Traverse	Ft. Sill, Yuma Proving Ground	t, w, t_f, t_p several traverses containing a variety of terrain conditions	Average speed, terrain factors, observation notes, driver comments	Comparative speed performance with several vehicles	WES	109-118	$10000
Ride	Ft. Sill, Vicksburg	t, w, l, t_f, t_p three firm courses varying in rms elevation	Speed, vertical acceleration at selected points on vehicle, terrain factors, observation notes, driver comments	Comparative ride performance with several vehicles	TACOM	119-128	$10000
					Totals	20 days	$20,000

* See table A3 for legend.

Table A10

Test Schedule and Costs

Test Activity	Time, Workdays No.	Time, Workdays Accumulative	Costs ($1000) TACOM	Costs ($1000) WES	Costs ($1000) Total	Costs ($1000) Accumulative Total
1. Shakedown tests						
Functional checkout	2	2	0	0	0	
Characteristic measurements	4	6	0	0	0	
Break-in runs	4	10	0	0	0	
2. Track tests						
Trail	14	24	10	5	15	15
Cross-country traverse	13	37	7	3	10	25
Special terrain conditions	19	56	10	15	25	50
3. Suspension tests						
Drop	31	87	12	0	12	62
Discrete obstacles	11	98	8	0	8	70
4. Handling tests						
Slalom	2	100	1	0	1	71
Constant radius	3	103	1.5	0	1.5	72.5
Lane change	3	106	1.5	0	1.5	74
Sudden right angle turn	2	108	1	0	1	75
5. Dynamic Response Field Evaluation Tests						
Cross-country traverse	10	118	0	10	10	85
Ride	10	128	10	0	10	95
6. Report	22	150	2	3	5	100
TOTALS		150	64	36		100

TABLE A11

SUMMARY OF TIME SCHEDULE AND COSTS

TEST ACTIVITY	TIME - WEEKS (1 2 3 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34)
1. Shakedown tests	*
2. Track tests	$50,000
3. Suspension tests	$20,000
4. Handling tests	$5,000
5. Dynamic response field evaluation tests	$20,000
6. Report	$5,000
TOTALS	33 Weeks (8 months) $100,000

*Previously authorized funds to be used.

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13. ABSTRACT

The interim Wheel/Track Convertible Test Rig, a uniquely suspended 8x8 wheeled vehicle that uses wrap-around tracks for improved performance, was tested in a variety of terrain conditions at Houghton, Michigan, and at Vicksburg, Mississippi, and in soil bins in a facility at Vicksburg. Tests were conducted to: evaluate the feasibility of the concept, determine if the track would stay on, observe interaction at the wheel-track interface to determine any possible slippage, determine ride and handling characteristics of the Wheel/Track Test Rig, which uses powered road arm suspensions, and evaluate and compare performance of the Test Rig with that of other available vehicles in tests on trails, cross-country traverses, special terrain, and laboratory-prepared soils. The Wheel/Track Test Rig performed well in a variety of terrain conditions; generally its performance equaled or exceeded the performance of both wheeled and tracked comparison vehicles. Vehicle ride and handling characteristics were considered better than those of the comparison vehicles. Test rig performance in soil in the wheel mode was impressive: a drawbar pull/weight coefficient of 0.96 was obtained on a clay soil prepared in the laboratory to a strength of 66 RCI, and a field experimental one-pass vehicle cone index of 11 was obtained. No wheel-track slip occurred during any of these tests, including tests on soft buckshot clay in which the vehicle running gear accumulated 1600 lb of mud (on a 6700-lb vehicle). Based on these tests, the Wheel/Track Convertible locomotion system is practicable, and the ride, handling, and performance of the Wheel/Track Test Rig suggest advanced testing, following any future design modifications. Appendix A presents the plan of tests followed in this program.

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